Ecological approach to differentiating podzols in coastal southwestern British Columbia

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ABSTRACT

A contemporary review of podzolization is given and several taxonomic classification systems of Podzols used in Europe and North America are compared. The taxonomic differentiae used for the separation of selected great groups and subgroups of the Podzolic Order in the current classification system (CSSC 1978) are tested against those of a new system. An ecological approach to classification is adopted which accepts the contemporary concepts and definitions while redefining the subdivisions within the Podzolic Order. The new classification recognizes five great groups differentiated according to differences in the properties of the podzolic B horizon. Classification at the subgroup level is based on the kind and degree of expression of organic, umbric, and albic horizons.

The current and new classification systems are tested on 177 Podzol pedons. Average distance cluster analysis is employed to determine the degree of similarity among profiles by using multi-horizon and multi-parameter data. In the analysis based on the new differentiae each major cluster corresponds to a tentative great group except one. The separation based on the CSSC (1978) differentiae produces four major clusters, each having a different combination of horizons and chemical properties; however, the clusters are not directly comparable to the recognized great groups. The five great groups and four subgroups of the tentative classification are shown to be related to regional climate, lithology of parent materials, moisture regime, and vegetation.

TABLE OF CONTENTS

ABSTRACT iii

TABLE OF CONTENTS iv

LIST OF TABLES vi

LIST OF FIGURES ix

ACKNOWLEDGEMENTS x

INTRODUCTION 1

PODZOLS 2

Characteristics of Podzols 2
Podzolization 3
Contemporary Classifications of Podzols 5

A NEW CLASSIFICATION OF PODZOLS 11

THE STUDY AREA 14

MATERIALS AND METHODS 18

Sampling 18
Soil Analysis 18
Numerical Analysis 19
Data Synthesis 22

RESULTS AND DISCUSSION 23

Results of Numerical Analysis 23
The CSSC (1978) Classification 23
The New Classification 24
Comparison of Groupings Created Through Cluster Analysis for the CSSC (1978) and New Classifications 28

Climatic Variation Within the Mesothermal Podzols 36
Surface Organic Layers 38
Podzolic B Horizons 40

Characterization and Classification of Mesothermal Podzols 46
Surface Organic Layers 46
Podzolic B Horizons 48
Horizonation and Depth Functions of Total Carbon and Sesquioxides . 55
Relationships Between the New Great Groups and Climate 60

Characterization of the New Great Groups 63
Humic* Podzols 63
Ferro-Humic* Podzols 64
Humo-Ferric* Podzols 67
Ferric* Podzols 70

The Use of Organic Layers and Non-Podzolic Mineral Horizons as Differentiae at the Subgroup Level 73
Folisolic* Subgroups 73
Umbric* Subgroups 75
Albic* and Spodic* Subgroups 76

SUMMARY 78

LITERATURE CITED 80

APPENDIX. Some Chemical Properties of Mesic Mesothermal Podzols 85

LIST OF TABLES

1	Comparison of five taxonomic systems for the classification of Podzols at the great group level	8
2	Comparison of five taxonomic systems for the classification of Podzols at the subgroup level	10
3	Taxonomic differentiae for great groups and subgroups of Podzols used by CSSC (1978) and proposed in this study	12
4	Means of some physical and chemical properties of basal till C horizons of Podzols in the study area	16
5	Example of grouping three pedons by chemical data	21
6	Horizon sequence of clusters based on the CSSC (1978)	24
7	Horizon sequence of subdivided B, C, and D clusters from Table 6	24
8	Horizon sequence of clusters based on the new classification	27
9	Horizon sequence of subdivided B, C, D, E, F, and G clusters from Table 8	27
10	Distribution of pedons within the major clusters of the CSSC (1978) and new classification	28
11	Distribution of pedons in the subdivided clusters of the CSSC (1978) and new classifications	31
12	Means and standard deviations of climatic data for biogeoclimatic units in the study area	37
13	Weighted means and standard deviations of selected chemical properties for the surface organic layer of mesic Podzols	39
14	Weighted means and standard deviations of selected chemical properties for the master B horizon of mesic Podzols	41
15	95 percent confidence limits for total C in the master B horizons of mesic Podzols	43
16	Frequency and thickness of albic horizons and sesquioxide contents in the master podzolic B horizon of spodic and albic mesic Podzols in relation to climate and parent materials	44

17 Synopsis of new great groups and subgroups 47

18 Weighted means and standard deviations of some chemical properties of the surface organic layer for new great groups . . 47

19 Weighted means and standard deviations of some chemical properties of the master podzolic B horizons for new great groups 49

20 Means and standard deviations of total carbon and sesquioxides of the podzolic B horizons diagnostic for the new great groups 51

21 Jacknifed classification matrix 52

22 Correlation matrix for total carbon and extractable sesquioxides of the podzolic B horizons diagnostic for tentative great groups 54

23 Weighted means and standard deviations for total C, oxalate and pyrophosphate Fe and Al of mesothermal Podzols classified in the new great groups 56

24 Relationship between the new great group and biogeoclimatic units 61

25 Weighted means and standard deviations of some chemical properties for layers and horizons and master layers and horizons of 22 Humic* Podzols 64

26 Weighted means and standard deviations of some chemical properties for layers and horizons and master layers and horizons of 40 Ferro-Humic* Podzols 66

27 Weighted means and standard deviations of some chemical properties for layers and horizons and master layers and horizons of 65 Humo-Ferric* Podzols 69

28 Weighted means and standard deviations of some chemical properties for layers and horizons of 10 Lithic (Humo-Ferric*) Podzols separated in clusters 69

29 Weighted means and standard deviations of some chemical properties for layers and horizons and master layers and horizons of 50 Ferric* Podzols 71

30 Weighted means and standard deviations of some chemical properties of subsurface H or Oh horizons diagnostic for folisolic* subgroups 74

31 Weighted means and standard deviations of some chemical properties of Ah or Ahe horizons diagnostic for umbric* subgroups 74

32 Weighted means and standard deviations of some chemical properties of Ae horizons diagnostic for albic* subgroups 74

33 Weighted means and standard deviations of some chemical properties of master podzolic B horizons of albic* and spodic* Podzols 77

LIST OF FIGURES

1 Average distance grouping in two dimensions 21

2 Mean and range values of total C for horizons and clusters based on the CSSC (1978) differentiae 25

3 Mean and range values of pyrophosphate Fe for horizons and clusters based on the CSSC (1978) differentiae 25

4 Mean and range values of pyrophosphate Al for horizons and clusters based on the CSSC (1978) differentiae 26

5 Mean and range values of total C for horizons and clusters based on the differentiae of this study 29

6 Mean and range values of pyrophosphate Fe for horizons and clusters based on the differentiae of this study 30

7 Mean and range values of pyrophosphate Al for horizons and clusters based on the differentiae of this study 30

8 Mean and range values of total N for horizons and clusters based on the CSSC (1978) differentiae 35

9 Mean and range values of total N for horizons and clusters based on the differentiae of this study 35

10 Depth functions of total C and extractable sesquioxides within the pedon of fine-loamy Umbric* Ferric* Podzol with Vermimull on alluvial terrace 58

11 Depth functions of total C and extractable sesquioxides within the pedon of coarse-skeletal Spodic* Ferro-Humic* Podzol with Mormoder on basaltic till 58

12 Depth functions of total C and extractable sesquioxides within the pedon of sandy Albic* Ferric* Podzol, gleyed phase, with Humimor on glaciofluvial materials 60

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INTRODUCTION

Considerable attention has been given to the study of Podzols in coastal south-western British Columbia. In addition to soil surveys or studies concerned largely with the description and mapping of soils, several ecological and pedogenic studies have been carried out in the area (McMinn 1957; Lesko 1961; Orloci 1961, 1964; Bhoojedhar 1969; Brooke et al. 1970; Cordes 1972; Roehmer 1972; Broersma 1973; Baker 1974; Kojima and Krajina 1975; Lewis 1976; Lowe and Klinka 1981; Moon 1981). Soil surveys in this area are currently being expanded by the B.C. Ministry of Agriculture, B.C. Ministry of Environment, Agriculture Canada, and members of the private sector.

The Ecological Program Staff of the B.C. Ministry of Forests has been studying forest ecosystems in the Vancouver Forest Region since 1975. These studies have detected some inconsistencies in relating Podzols to their factors of formation. Specifically, weak relationships between regional climates and great groups have been noticed; and, at the subgroup level, inadequate importance given to the presence or absence of thick terrestrial organic horizons and melanized or eluviated mineral horizons in recognizing both ecologically and pedogenetically significant taxa. A review of other classifications used in North America and Europe indicated that, some useful features notwithstanding, they do not offer the satisfactory solution to the above problems. Therefore, it was decided to test the usefulness of the current classification of Podzols as defined by CSSC (1978) using the data available from the Ecological Program Staff in the Vancouver Forest Region.

In the first part of this study, characteristics of Podzols, podzolization, and contemporary classifications of Podzols are reviewed. A new classification, and data and methods used for testing are then described. Numerical classification of the data, comparison of recognized and new taxa, and discussion dealing with pedogenic and interpretive significance of the new taxa follow.

PODZOLS

Characteristics of Podzols

Podzols were first described and classified according to their mode of origin by Dokuchaev in the 1870's. Since Dokuchaev's time, genesis of Podzols has been explained by extremely wide-ranging hypotheses as to the processes involved. The classification of Podzols has also been subject to many different interpretations. In the USSR, Podzols are still classified by a combination of morphological and climatic characteristics. In Europe, Podzols must have distinct morphological characteristics but the zonal concept is not used. In the American and Canadian systems, Podzols are classified on the basis of B horizon properties; the diagnostic characteristic is now the spodic (podzolic) B horizon that has been enriched with sesquioxides, organic matter, or both.

According to Duchaufour (Petersen 1976), Podzols are characteristically found in humid microthermal and mesothermal climates where the precipitation exceeds the actual evapotranspiration, thereby leaving a considerable quantity of water to leach through the soil. Podzols typically have Mor humus forms and are usually associated with coniferous forests - both common features of microthermal climates - although Petersen (1976) states that these characteristics are not requisite as Podzols are quite common in the tropics.

Podzols develop particularly well on coarse-textured parent materials, rich in quartz. Soil Survey Staff (1975) states that Spodosols do not form on clayey (greater than 35% clay) parent materials. However, many scientists (Zonn 1973, Duchaufour 1976) have shown that Podzols do form on clay-rich parent materials - usually preceded by the eluviation of fine clay particles through a process known as lessivage.

Podzols have no specific drainage characteristics (Petersen 1976). Most authors (e.g., Ponomareva 1969, Petersen 1976) state that Podzols may develop on well drained sites as well as on sites where the drainage for some reason is restricted. Podzols are always acidic. Petersen (1976)

states that in fully developed Podzols, the acidity of the upper horizons will be about pH 4, often below pH 4. In general, the lowest pH values are found in the upper horizons with acidity decreasing with increasing depth. This low pH is due to a very low base saturation and a relatively high content of organic acids. At pH 4, percent base saturation is effectively zero. Because of the often sandy texture, and the nature of translocated inorganic compounds (mainly sesquioxides), much of the cation exchange capacity in the eluvial and illuvial horizons is due to organic matter and is largely pH-dependent.

Podzolization

Present-day literature appears to have eliminated many of the early theories on the genesis of Podzols through more recent findings. It now appears as though a general consensus is beginning to form among many workers. The emerging concept of podzolization has not been fully supported through positive research findings and will likely be subject to continual modifications as further research results are gained.

In general, podzolization is now thought to occur as a result of acidic organic molecules, from simple organic acids to large complex polymers such as humic and fulvic acid, forming organo-metallic complexes and chelates with iron and alumnium. These organic compounds originate from either the biological breakdown of organic material of floral or faunal origin or as components of canopy drip and other leaf leachates (Malcolm and McCracken 1968). These organic compounds have been shown to have a high number of acidic functional groups, most notably - COOH, phenolic -OH, alcoholic -OH, NH_2 and quinones. Petersen (1976) found that these groups will, to some extent, dissociate, bringing about the release of a H-ion, causing the compounds to become negatively charged even at a relatively low pH.

Because of charges due to this partial dissociation of acidic functional groups and their hydrophilic character these organic compounds tend to repel each other and form discrete particles surrounded by H_2O molecules. This makes a complete dispersion in water possible, a necessary condition for their mobilization (DeConninck 1980).

As long as these organo-metallic compounds maintain a sufficient negative charge and a moderate size they will remain mobile and can be moved downward through the soil. As more polyvalent cations, such as Fe^{+3} and Al^{+3} are complexed, the negative charge becomes neutralized and the complexes increase in size. This leads to a decrease in mobility and eventual precipitation.

Dehydration and transformation into the solid state is believed to gradually occur. Van der Waal's forces and protonic bridges can then form as the unbound parts of these organo-metallic substances are able to approach each other. Once many Van der Waal's bonds and protonic bridges have been established these bonded agglomerates become very stable, opposing the penetration of H_2O molecules, causing the solid to become partially hydrophobic (DeConninck 1980).

It is through this process that the podzolic B horizon (CSSC 1978) or spodic horizon (Soil Survey Staff 1975) is thought to be formed. This hypothesis emphasizes the importance of negatively charged organic substances. These organic substances are thought to be responsible for the decomposition and removal of minerals in the surface horizons as well as their eluviation in complex or chelate form. Since their eventual precipitation depends on the availability of polyvalent cations capable of neutralizing the net negative charge, this podzolic B horizon can occur at almost any depth. If the soil is fine-textured, relatively young, and the parent material contains a high concentration of polyvalent cations, the podzolic B horizon can form almost at the surface of the mineral soil with no eluviated horizon in evidence. If the parent material has a low concentration of polyvalent cations or is relatively old, the podzolic B horizon may be at some depth, with a thick Ae horizon overlying.

A new hypothesis for the movement and precipitation of sesquioxides and organic matter into the podzolic B horizon has recently been suggested by Farmer et al. (1977, 1980, and 1982). Aluminum, iron, and silicon move from the Ae horizon to the podzolic B horizon with positively charged inorganic sols. Farmer et al. (1982) suggests that Al and Fe are present predominant in inorganic forms in the podzolic B horizons: Al as imogolite and

proto-imogolite allophanes, and Fe as a separate oxide phase. Organic matter then migrates through the Ae horizon, if present, and precipitates on the positive colloids at the top of the podzolic B horizon.

Contemporary Classifications of Podzols

Because podzolization appears to be primarily determined by the presence of organic substances with active acidic functional groups and the availability of polyvalent cations capable of neutralizing these negatively charged substances through complex formation, the amount of iron and aluminum as well as organic matter present in the B horizon is likely to be a part of any classification of Podzols. The CSSC (1978) defines Podzols on the basis of a combination of morphological and chemical criteria of the B horizon. Soils of the Podzolic Order must meet the following morphological and chemical criteria:

1. the podzolic B horizon is at least 10 cm thick and has moist, crushed colour as follows:

    a. the colour is black or hue is either 7.5YR or redder or 10YR near the upper boundary and becomes yellower with depth; and

    b. the chroma is higher than 3 or the value is 3 or less.

2. the accumulation of amorphous materials in the podzolic B horizon is indicated by:

    a. brown to black coating on some mineral grains or brown to black microaggregates; and

    b. a silty feel when rubbed wet unless the material is cemented.

3. the texture of the podzolic B horizon is coarser than clay;

4. the soil either has no Bt horizon or the upper boundary of the Bt horizon is at depth greater than 50 cm from the mineral surface; and

5. the soils have a B subhorizon (Bh) at least 10 cm thick that contains more than 1% organic C, less than 0.3% pyrophosphate-extractable Fe, and has a ratio of organic C to pyrophosphate-extractable Fe of 20 or more.

6. alternatively, the soils have a B subhorizon (Bf or Bhf) at least 10 cm thick with the following characteristics:

   a. an organic content of more than 0.5%;

   b. a pyrophosphate-extractable Fe and Al content of 0.6% or more in textures finer than sand and of 0.4% or more in sands;

   c. a ratio of pyrophosphate-extractable Fe and Al to clay of more than 0.05; and

   d. a ratio of organic carbon to pyrophosphate-extractable Fe of less than 20, or pyrophosphate-extractable Fe is at least 0.3% or both.

A Bf horizon contains 0.5-5% organic C, and a Bhf horizon contains more than 5% organic C. Any B horizon that satisfies the above morphological and chemical criteria is a podzolic B horizon. However, if the B horizon is less than 10 cm thick, the pedon does not qualify as a Podzol. Satisfying the depth criterion, the Bh horizon is diagnostic for Humic Podzols, the Bhf horizon is diagnostic for Ferro-Humic Podzols, and the Bf horizon is diagnostic for Humo-Ferric Podzols. These diagnostic horizons express the varying role of different components in the podzolization process and the categorical level of great group is based on the relative strengths of these components' expression.

In the Canadian system of soil classification, Podzols must have a B horizon in which the dominant accumulation product is "amorphous" material composed mainly of humified organic matter combined in varying degrees with Fe and Al. In this system, it is the accumulation of organo-metallic agglomerates that is stressed - not the eluviation of these components. These organo-metallic agglomerates can form either in situ in the upper limits of the mineral soil or after eluviation as negatively charged, soluble organo-metallic complexes. A classification at the great group level based on the characteristics of the B horizon also avoids problems encountered in disturbed soils where surficial horizons may no longer accurately reflect the nature of the subsurface horizons.

Recent works of Farmer et al. (1977, 1980, 1982) in reassessing podzol formation processes have repercussions on the choice of chemical criteria for defining podzolic B horizons. It was suggested that the amounts of

Al and Fe in organic complexes as measured by pyrophosphate extraction is a secondary process in podzol formation. Locally, Moon's (1981) study of three Podzol-like soils on East Vancouver Island showed inconsistency in using pyrophosphate Fe and Al as a single, definitive chemical criterion in classifying Canadian Podzols.

Once the criteria of the Podzolic Order are defined, the definition of more specific classes of the hierarchy can follow. The current Canadian system (CSSC 1978) subdivides the Podzolic Order into three great groups: Humic Podzol, Ferro-Humic Podzol, and Humo-Ferric Podzol as defined above. These great groups are related in Table 1 to comparable taxa of the former Canadian (NSSC 1970), American (Soil Survey Staff 1975), Kubiena's (1953), and German (Muckenhausen 1977) systems.

Examination of Table 1 suggests that a similar approach to the classification of Podzols has been adopted despite difficulties in establishing exact correlations among the taxa. These difficulties are caused mostly by differences in chemical criteria or their absence for diagnostic podzolic B horizons. Each taxonomic system examined recognizes three taxa at the great group or comparable levels[1]. The American system separates Spodosols that have an aquic moisture regime, i.e., either they have a shallow fluctuating ground water table or the climate is extremely humid, from those that are more or less freely drained. Thus, some Aquods (e.g., Cryaquods and Sideraquods) were included for comparative purpose in Table 1.

Humic Podzols, Humods, or Humus Podzols are described as Podzols that have a large accumulation of organic carbon relative to iron. It might be erroneous to compare European Humus Podzols to Humic Podzols or Humods, although the morphological descriptions indicate that such comparison could be correct, at least in some cases. It is probable that some Humus Podzols might be classified as Ferro-Humic Podzols using the Canadian system. The

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[1] Ferrods, however, are not known to occur in the United States. They are Spodosols that have large accumulation of free iron relative to organic carbon, thus completing a conceptual series of illuviation of organic carbon and sesquioxides.

TABLE 1. Comparison of five taxonomic systems for the classification of Podzols at the great group level

CSSC (1978)[1]	NSSC (1970)[2]	Soil Survey Staff (1975)[3]	Kubiena (1953)[4]	Muckenhausen (1977)[4]
Humic Podzol	Humic Podzol	Humods (-Aquods)	Humus Podzol	Humus Podzol
Ferro-Humic Podzol	Ferro-Humic Podzol	(Humic subgroups of Cryorthods, Fegiorthods and Haplorthods)		
		Orthods (-Aquods)	Iron-Humus Podzol	Iron-Humus Podzol
Humo-Ferric Podzol	Humo-Ferric Podzol	Typic subgroups of Cryorthods, Fragiorthods and Haplorthods	Iron Podzol	Iron Podzol
?	?	Ferrods	?	?

[1] Diagnostic horizon for the great groups were defined in the preceding text.

[2] The diagnostic Bh horizon for the Humic Podzols is at least 10 cm thick; when moist it has a colour with value and chroma of less than three; it contains more than 2% organic matter but very little or no free Fe; it does not turn redder on ignition and the ratio of organic matter to free (oxalate-extractable) Fe is 20 or more. Usually, the difference between oxalate-extractable Fe and Al in Bh and IC horizons is less than 0.8%.

The Bhf(> 10% organic matter), Bfh (5-10% organic matter) and Bf (< 5% organic matter) are the diagnostic horizons for the Ferro-Humic and Humo-Ferric great groups, respectively. These horizons are all enriched with hydrated iron. They usually have a chroma of three or more. They contain 0.8% or more oxalate- extractable Fe and Al than IC horizon, and the ratio of organic matter to oxalate-extractable Fe is less than 20.

[3] Soil Survey Staff (1975) defines Spodosols as mineral soils that have a spodic horizon that has its upper boundary within 2 m of the surface. The description, characterization, and complete requirements for the spodic horizons are given by Soil Survey Staff (1975), pp. 29-32. Humods are Spodosols that have, in 50 percent or more of each pedon, a spodic horizon that has a subhorizon in which the ratio of free iron (by dithionite-citrate) to carbon (both elemental) is > 0.2. Orthods are Spodosols that have a spodic horizon that has in some subhorizon a ratio of percent free iron to percent carbon of < 6 and that has in all subhorizons a ratio between percentages of the same two elements of 0.2 or more. Ferrods are Spodosols that have a spodic horizon that has, in all subhorizons, a ratio of percent free iron to percent carbon of 6 or more.

[4] The Bh (humus) horizon of Podzols refers to the aqua-brown horizons enriched predominantly by organic matter; the Bs (sesquioxidic, after Pallman 1935) refers to the rust-yellow to rust-brown horizons enriched predominantly by the sequioxides of Fe and Al; the Bhs horizon of Podzols refers to a horizon that is rich in sequioxides and contains visible amounts of humus. More detailed description and characteristics for the taxa are given by Kubiena (1953).

CSSC (1978) and NSSC (1970) indicate that Humic Podzols are distributed under Sphagnum, heath, and forest vegetation of wet, western coastal ecosystems in maritime fringe environments or at high elevations inland. It appears, however, that Humic Podzols, with the exception of the upper (parkland) subzone of the subalpine Mountain Hemlock Biogeoclimatic Zone (Brooke et al. 1970), are extremely rare in submontane to montane, coastal southwestern British Columbia. Soil Survey Staff (1975) reports Humods only from high latitudes or high elevations in Alaska, the Adirondack Mountains, and a few areas in the southeastern USA.

Ferro-Humic and Humo-Ferric Podzols (Orthods or Iron-Humus and Iron Podzols) have a podzolic B horizon that has an accumulation of organic carbon, iron, and aluminum in which no single one of these elements is dominant. The major difference between CSSC (1978) and NSSC (1970) is in chemical criteria for extractable Fe and Al and the number of podzolic B subhorizons. The Orthods of the American system comprise the Ferro-Humic and Humo-Ferric Podzols; further differentiation is done at the subgroup level: typic subgroups contain less than 6%, and humic subgroups contain more than 6% of organic C in the upper 10 cm of the spodic horizon. In the Canadian system, differentiation between Humo-Ferric and Ferro-Humic Podzols is done at the great group level using values of organic C less than 5% and more than 5%, respectively. Based on morphological criteria, Iron-Humus and Iron Podzols of the European systems appear to be correlated with the Canadian system.

Ferro-Humic and Humo-Ferric Podzols are the most common Podzols in North America and Europe. They have formed mainly on coarse, base-poor soil materials under coniferous, broadleaf, or mixed coniferous-broadleaf forests.

At the next lower category (i.e., the subgroup level in the Canadian system), the taxonomic importance given to organic horizons, and umbric (melanized) or albic (eluviated) horizons of Podzols is examined (Table 2).

In the European systems the properties of the upper solum of Podzols are largely incorporated at the subtype (great group) level; e.g., umbric and albic horizons are included in the characteristic horizon sequence for each subtype of Podzol Type (Order). Lower ranking taxa (varieties) of the European systems comparable to subgroups, are not usually listed in the classification synopsis. They are described as quantitative modifications of subtypes, differentiated by the thickness and consistence of podzolic B horizons, humus form, and thickness and expression of the albic horizon; designated by a combination of appropriate adjectives. The American system features great groups or subgroups that do not reflect, with a single exception of a histic subgroup, the kind, arrangement and degree of expression of the soil horizons overlying a spodic horizon. Undoubtedly

TABLE 2. Comparison of five taxonomic systems for the classification of Podzols at the subgroup level

Layer or horizon	CSSC (1978)	NSSC (1970)	Other taxonomic systems
Surface organic layer	Folisolic phase[1] (the surface organic layer is more than 15 cm but less than 40 cm thick)	Peaty phase (the surface organic layer is more than 15 cm but less than 40 cm thick)	Histic subgroup of some Aquods (Soil Survey Staff 1975) Highmoor Podzol[2] (Muckenhausen 1977)
Umbric horizon	Sombric Ferro-Humic or Humo-Ferric Podzol (Ah horizon is at least 10 cm thick)	Sombric Ferro-Humic or Humo-Ferric Podzol (Ah horizon is at least 7.5 cm thick)	Phases in the American system; non-formal taxa in the Kubiena's (1953) and Muckenhausen's (1977) systems
Albic horizon	Orthic subgroup of a Podzol (or albic phase)	Orthic subgroup of a Podzol (Ae horizon is at least 2.5 cm thick)	
Umbric or albic horizon is absent or does not meet the thickness criteria	Orthic subgroup of a Podzol (or mini phase)	Mini Ferro-Humic or Humo-Ferric Podzol (A horizon is absent or less than 2.5 cm thick)	

[1] Trowbridge (1980).

[2] Hochmoor-Podsol was translated as Highmoor-Podzol. This taxon, however, is recognized at the subtype (great group) level of the German system.

these properties can be used as differentiae at lower categories or for phases. The rationale for this is to mininize the effect of changes in the surficial 25 cm layer on classification of soils at higher levels of generalization. It is the Canadian system that gives some taxonomic importance to the upper, non-podzolic horizons of Podzols. The former NSSC (1970) classification, however, was more specific in recognizing orthic, mini, and sombric subgroups. The present CSSC (1978) system recognizes only orthic and sombric subgroups. Podzols with excessively thick surface organic horizons are treated as a folisolic phase - an equivalent to the peaty phase of the former system.

A NEW CLASSIFICATION OF PODZOLS

Lewis (1976) applied an ecosystem approach in a genetic study of mesothermal, till-derived Podzols on Vancouver Island. He sampled non-lithic, moderately well drained, glacial till-derived Podzols of lithologically distinct tills in the drier and wetter subzones of the Coastal Western Hemlock (CWH) Biogeoclimatic Zone (Krajina 1969). He studied the effects of climate and geology on Podzol genesis, characterized the Vancouver Island model of Podzols, and proposed that the present concept of podzol genesis be broadened.

The present study extends Lewis' (1976) work to classification of the Podzolic Order, i.e., the contemporary concept and definition of Podzols was adapted but their subdivision was modified. The working hypothesis assumed that the Podzolic Order (CSSC 1978) might be subdivided according to effects of climate, lithology of parent materials, relief, and vegetation into more integral taxa than those recognized presently.

Podzols included in this study were sampled in submontane to montane ecosystems, formed on a variety of parent materials, and under the influence of a number of regional climates recognized in coastal southwestern British Columbia. Subalpine Podzols were not sampled; thus, the proposed classification model did not test the Humic Podzol Great Group as they were not included in the soils studied. Consequently, the classification model was designed to provide for four great groups devised to represent Ferric*, Humo-Ferric*, Ferro-Humic*, and Humic* Podzols (Table 3). On a relative basis, the Humic* Podzol Great Group is characterized by the highest content of organic carbon and extractable sesquioxides. To avoid confusion in horizon symbols and nomenclature, all diagnostic horizons or taxa of the new classification that have been redefined or renamed are marked by an asterisk (*), Humic Podzols (Humods) proper are further referred to as Humus* Podzols. In fact, this designation might be more appropriate since this adjective would differentiate Humus* Podzols from all other Podzols.

The described variations of podzolic B horizons were correlated with surface accumulation of organic materials (the kind and thickness of humus

TABLE 3. Taxonomic differentiae for great groups and subgroups of Podzols used by CSSC (1978) and proposed in this study

CSSC (1978)[1]				This study [2]			
Layer or horizon	Differentia	Value	Diagnostic for a taxon	Layer or horizon	Differentia	Value	Diagnostic for a taxon
Bh	C	1%	Humic great group	Bh	C	1%	Humus* great group
Bhf	C	5%	Ferro-Humic great group	Bh*	C	10%	Humic* great group
				Bhf*	C	6-10%	Ferro-Humic* great group
Bf	C	0.5-5%	Humo-Ferric great group	Bfh*	C	3-5.9%	Humo-Ferric* great group
				Bf*	C	3%	Ferric* great group
LFH	C combined thickness	>17% 15-40 cm	(Folisolic phase)	LFH	C combined thickness	>17% 15-40 cm	Folisolic* subgroup
Ah	C thickness	≤17% ≥10 cm	Sombric subgroup	Ah	C thickness	≤17% ≥2 cm	Umbric* subgroup
Ae	C	≤17%	(Albic phase)	Ae	C thickness	≤17% ≥2 cm	Albic* subgroup
Ah or Ae is absent			(Mini phase)	Ah or Ae is absent			Spodic* subgroup

[1] Complete definitions of taxa are given by CSSC (1978).

[2] Definitions of horizons follow CSSC (1978) or Soil Survey Staff (1975), and definitions of taxa follow CSSC (1978) with the exception of those characteristics which were redefined in this study.

form), and the expression and thickness of albic and umbric horizons. Due to the considerable ecological and interpretive significance of these horizons, the classification model tested four subgroups designated as folisolic*, albic*, umbric*, and spodic* (Table 3). The term spodic* is equivalent to Lewis' (1976) designations of mini, mini-lateritic, or cryptic. The folisolic* subgroup has been placed with Podzols having excessively thick surface organic horizons, the albic* subgroup with Podzols featuring albic horizons, the umbric* subgroup with Podzols featuring umbric horizons, and the spodic* subgroup with Podzols lacking either albic or umbric horizons.

CSSC (1978) differentiates subgroups on the basis of the kind and arrangement of horizons that indicate:

1. conformity to the central concept of the great group;
2. intergrading toward soils of another order; or
3. additional special features within the control section.

At the great group level Soil Survey Staff (1975) consider the whole soil, the assemblage of horizons, and the most significant properties selected on the basis of the numbers and importance of accessory properties. The differentiae at the great group level place soils together that should have the following properties in common:

1. close similarity in kind, arrangement, and degree of expression of horizons;
2. close similarity in soil moisture and temperature regimes; and
3. similarity in base status.

It appears, however, that the suggested attributes are inadequately reflected at the subgroup level of the Canadian and American systems. These attributes should support the proposed subgroups in the new classification. At the great group level, Podzols are classified according to differences in soil-forming processes as expressed in the podzolic B horizon; hence, the classification at the next level should include the kind, arrangement, and degree of expression of organic, umbric, and albic horizons.

THE STUDY AREA

This study was carried out in the CWH Zone. This zone is the wettest mesothermal zone of British Columbia and largest in the Vancouver Forest Region. Its climate is characterized as Cfb (Koppen/Trewartha in Trewartha 1968); i.e., mesothermal, with no distinct dry season, precipitation of the driest month over 13 mm, and a cool summer with the mean monthly temperature of the warmest month below 22°C (Krajina 1969).

Western hemlock [Tsuga heterophylla (Raf.) Sarg.] is usually the most common tree species in forest communities. It regenerates in abundance under the canopy of forest stands especially if the forest floor has a well developed Mor humus form. If undisturbed, it has the greatest potential to dominate the forest cover. Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] and western redcedar (Thuja plicata Donn ex D. Don in Lamb.) occur frequently, while amabilis fir [Abies amabilis (Dougl.) Forbes] and yellow-cedar [Chamaecyparis nootkatensis (D. Don) Spach.] are common in the wetter parts of the zone. The present distribution of tree species has been modified by past disturbances and characteristics of the site, in particular soil moisture and nutrient regime. The predominance of several moss species [Hylocomium splendens (Hedw.) B.S.G., Rhytidiadelphus loreus (Hedw.) Warnst. and Plagiothecium undulatum (Hedw.) B.S.G.] and the low occurrence of herbs along with the high species significance of western hemlock are the floristic characteristics of mesic and mesotrophic ecosystems, represented by the Tsuga heterophylla-Rhytidiadelphus (loreus) Plant Order.

Accumulation of acid decomposition products on the forest floor, leaching, eluviation, illuviation, and gleying were described by Krajina (1969) as the prevailing pedogenic processes characteristic of the zone. The dominant soils are Humo-Ferric or Ferro-Humic Podzols with Mor humus forms. Accumulation of weathered products is slow since it is counteracted by organic acids destroying clay minerals.

Three localities within the CWH Zone were selected for the study:

1. the Cameron River Valley, near Port Alberni on central Vancouver Island;
2. the University of B.C. Research Forest, near Haney in the Lower Fraser Valley; and
3. the Koprino River Watershed, in Quatsino Sound on northern Vancouver Island.

Based on major vegetation and soil differences of ecosystems, the CWH Zone was subdivided into several subzones (Klinka et al. 1984). The three localities used in this study were in the Drier Maritime (CWHa), Wetter Maritime (CWHb), and the ecotone (CWHb/d) between Wetter Maritime and Hypermaritime (CWHd) subzones, respectively. Thus the study area contained submontane to montane ecosystems under the dominant influence of maritime mesothermal climate, differing mainly in precipitation, temperature, and soil parent materials.

In the Cameron River Valley the study was conducted in that part of Tree Farm License 19 (MacMillan Bloedel Ltd.) located within the driest and warmest part of the CWHa Subzone which may be considered transitional to the Wetter Maritime Coastal Douglas-fir (CDFb) Subzone. The area is characterized by a wetter Csb climate and is underlain by volcanic rocks; mainly altered basaltic and andesitic lavas. Glacial till and alluvial deposits are the most common parent materials (Table 4). The soils have a sandy to loamy texture, contain a variable content of coarse fragments, and are acidic with acidity decreasing with depth. The soils with a mesic moisture regime were identified as Humo-Ferric Podzols-Mini phase with Hemimor humus forms.

The forest communities of the Cameron River Valley represent submontane, old growth, near-climax ecosystems. They are dominated by Douglas-fir but contain significant amounts of western redcedar and, occasionally, western hemlock. The mesic and mesotrophic ecosystems characteristic for the CWHa Subzone are represented by the Tsuga-Pseudotsuga-Hylocomium Association. A more complete description of this area is given by Inselberg et al. (1982).

The study sites at the University of B.C. Research Forest are situated in both the CWHa and the montane variant of the CWHb Subzones; the former is

TABLE 4. Means of some physical and chemical properties of basal till C horizons of Podzols in the study area

Number of samples	Sand (%)	Silt (%)	Clay (%)	Texture	Coarse fragments (%)	pH (H_2O)	C (%)	CEC (meq/100g)	BS (%)
1. Cameron River Valley, CWHa Subzone[1]:									
5	40	41	19	loam	52	6.1	0.61	13.6	58.6
2. University of B.C. Research Forest, CWHa and CWHb subzones[2]:									
5	59	32	9	sandy loam	75	5.3	0.50	12.6	4.3
3. Koprino River Watershed, CWHb/d ecotone[3]:									
5	55	36	9	sandy loam	51	5.1	1.8	17.1	10.6

[1] From unpublished data, B.C. Ministry of Forests, Vancouver Forest Region.

[2] From Klinka (1976), Table 2, p. 42.

[3] From Klinka et al. (1980), Appendix, p.45.

located at lower elevations (less than approximately 600 m), the latter is mainly found at higher elevations (600 to 1000 m). The forest is characterized by a drier to wetter Cfb climate and is underlain by acid igneous rocks, mainly quartzdiorite. Glacial till is the most common soil parent material with loose (ablation) till overlying compacted (basal, lodgement) till (Table 4). The soils are typically coarse-textured (loamy sand to sandy loam) and are acidic, with acidity decreasing with depth. The soils with a mesic soil moisture regime were classified as Humo-Ferric or Ferro-Humic Podzols; Mini or Orthic phase with Hemihumimor humus forms.

The forests are dominated by western hemlock but contain significant amounts of western redcedar. Douglas-fir is common at lower elevations (CWHa) and amabilis fir is common at higher elevations (CWHb). The characteristic mesic and mesotrophic ecosystems for the CWHb Subzone are represented by the Tsuga(-Abies)-Rhytidiopsis Association. A more complete description of this area is given by Klinka (1976).

In the Koprino River Watershed the study was conducted in a part of

Tree Farm License 6 (Western Forest Products Ltd.), located in the CWHb/d ecotone, with two recognized altitudinal variants: submontane (0 to 600 m) and montane (600 to 950 m). This area is characterized by a cooler and wetter Cfb climate and is underlain by conglomerate rock, composed predominantly of volcanic coarse fragments (Table 4). Soils have a loamy texture (sandy loam to loam), and are acidic with acidity decreasing with depth. Soils with a mesic moisture regime were identified as Ferro-Humic Podzols; Folisolic or Mini phase with Humimor humus forms.

Forest communities in the watershed represent climatic climax ecosystems. They are dominated by western hemlock of excellent vigour but contain a significant amount of amabilis fir and western redcedar with some scattered Sitka spruce [Picea sitchensis (Bong.) Carr.]. The mesic and mesotrophic ecosystems characteristic for the area are represented by the Tsuga-Thuja-Rhytidiadelphus Association. A more complete description of the area is given by Klinka et al. (1980).

MATERIALS AND METHODS

Sampling

Sample plots (approximately 500 m^2 in size) were selected using a stratified non-random design so that each represented a sample of an individual ecosystem. On each plot the vegetation was analyzed by phytosociological techniques. The vegetation analysis included the listing and identification of all vascular plants, bryophytes, and lichens present on the plot, as well as an evaluation of species significance (abundance and dominance) and vigour according to vegetation strata (Brooke et al. 1970).

Each site was described in terms of elevation, position on the slope, slope gradient, exposure, geology, parent materials, and other features. Sampling, description, and classification of soils followed the Canadian Soil Survey Committee (CSSC 1978); humus forms were described and classified according to Klinka et al. (1981a).

Soil samples were collected by excavation from each horizon of the pedons which were selected to represent the prevailing soils within the established sample plots. The samples were dried at room temperature, crushed with a wooden roller, passed through a 2 mm sieve to remove the coarse fraction, and stored to await chemical analysis.

Detailed description and analyses of the soils from the University of B.C. Research Forest were presented by Klinka (1976); those from the Cameron River Valley and Koprino River Watershed were presented by Inselberg et al. (1982) and Klinka et al. (1980) respectively, or were deposited in the library of the B.C. Ministry of Forests, Vancouver Forest Region.

Soil Analysis

The < 2 mm fraction of the mineral soil and the ground LFH (composite ectorganic) horizon samples were analyzed for a number of properties. The following properties were used for the purposes of this study: pH ($CaCl_2$), total carbon (C%) and nitrogen (N%), exchangeable cations (Ca, Mg, K, Na meq/100g) and cation exchange capacity (CEC meq/100g), acid

ammonium oxalate- and sodium pyrophosphate-extractable iron and aluminum. All analyses followed Lavkulich (1978).

The pH of mineral horizons was measured with a pH meter in a 1:2 (w/v) soil: 0.01 M $CaCl_2$ suspension; for organic horizon samples a soil: solution ratio of 1:5 was used.

Total carbon was determined by dry combustion with a Leco Induction Furnace and Carbon Analyser (Laboratory Equipment Corporation, St. Joseph, Michigan).

Total nitrogen was determined by a semimicro-Kjeldahl procedure described by Bremner (1965), followed by colorimetric estimation of NH_4-N by a modification of the phenol-hypochlorite method.

Cation exchange capacity and exchangeable cations were determined using 1 M NH_4OAc adjusted to pH 7. The absorbed NH_4 was determined by a semimicro-Kjeldahl distillation procedure. The leached cations of calcium, magnesium, sodium, and potassium were determined by atomic absorption spectrophotometry.

Ammonium oxalate-extractable Fe and Al were extracted by shaking for four hours in the dark. The extract was then centrifuged at 2400 rpm for 10 minutes and the supernatent liquid was then analyzed for Fe and Al by atomic absorption spectroscopy.

Sodium pyrophosphate-extractable Fe and Al were extracted overnight at 25°C using a sodium pyrophosphate solution. Extracted Fe and Al were then determined by atomic absorption spectroscopy.

Numerical Analysis

The horizons used in the numerical analyses are given in Table 3. Only horizons of the LFH layer and A and B master horizons were used as chemical data for master C horizons were often incomplete. In a number of pedons the same type of horizon was present more than once and in such cases it was

decided for diagnostic purposes to use the highest total carbon value for all horizons except Ae horizons for which the lowest total carbon value was used.

In the cluster analysis for the CSSC (1978) classification chemical data of six diagnostic horizons were used, and for the new classification chemical data of eight diagnostic horizons were used. Both analyses utilized total C for LFH (or LF and H[1]), Ah, and Ae horizons, and both total C and oxalate and pyrophosphate Fe and Al for podzolic B horizons - a total of five chemical properties.

To facilitate the classification of 177 Podzol pedons an average distance cluster analysis (Ward 1963) was used. With this technique it is possible to determine the degree of similarity between different profiles using multi-horizon and multi-parameter data. The technique is best described on the basis of the following example described in Table 5 and Figure 1.

Values for total C for the LFH layers and Ah horizons were plotted in two dimensional space and the distances between the positions of these three points were measured using the Pythagorean theorem. It is obvious from Figure 1 that pedons 1 and 2 are closer to each other than pedon 3. They form the initial cluster and the distance between them can be considered as a degree of similarity. The closer the profiles are to one another, the more similar their properties. Once the initial cluster is formed, the mean value of the two profiles becomes the central point and the distance to the next nearest site is computed at a lower order of similarity so as to minimize the within-cluster variance of the new group.

In this way a hierarchy can be built up. In the present example only two dimensions, total C for LFH and Ah horizon, were considered. However, this scheme can easily be extended to n-dimensions by using matrix algebra. The UBC-C-GROUP program (Patterson and Whitaker 1973, 1978) was used for

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[1] On most sites a single composite sample was taken to represent forest floor (LFH layer). When an exceptionally thick H horizon was found underlying the LF layer, the LF layer and H horizon were sampled separately.

TABLE 5. Example of grouping three pedons by chemical data

Pedon	Chemical parameter/layer or horizon Total C (%)	
	LFH	Ah
Pedon 1	28.0	0.7
Pedon 2	35.0	1.5
Pedon 3	22.0	3.0

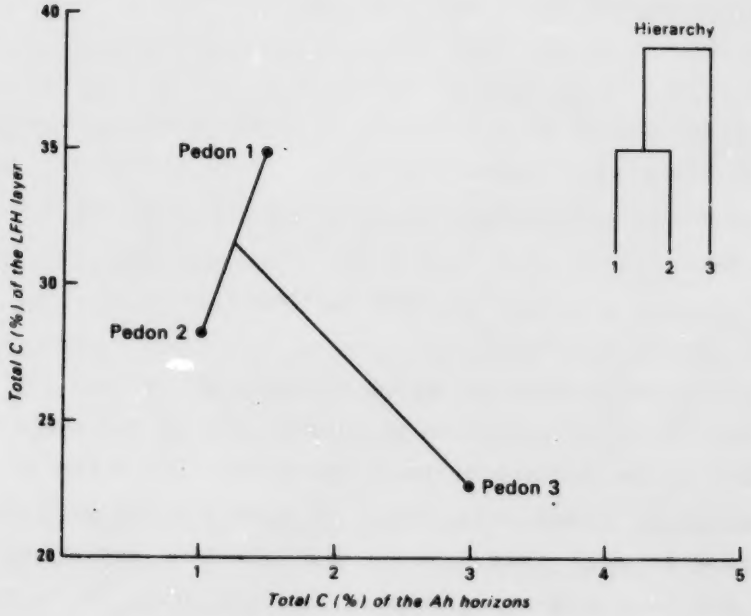

FIGURE 1. Average distance grouping in two dimensions.

this study to classify 177 Podzols using 14 different combinations of chemical properties and horizons. All profiles were grouped together according to their similarity with respect to all measured parameters. Such an approach should provide a comprehensive classification because all chosen parameters were considered simultaneously and of equal weight.

The data bank for the 177 Podzols were subjected to two analyses. In the first, the podzolic B horizons were defined according to CSSC (1978). This analysis used the following six layers and horizons: LFH (or LF and H), Ah, Ae, Bhf, and Bf. As mentioned earlier, Humic (Humus*) Podzols were not studied. In the second analyses the same horizons were defined according to the new classification model (Table 3). This analysis utilized eight horizons as follows: LFH (or LF and H), Ah, Ae, Bh*, Bhf*, Bfh*, and Bf*. This resulted in a greater number of horizons being incorporated into the new analysis. This was due to the fact that the analysis only utilized one horizon of each type within a pedon. When the horizons were separated even further in the new classification, formerly redundant horizons became available for use in the analysis.

Due to the nature of the average distance cluster analysis program used, missing horizons were counted as zeros. This caused the analysis to group on the presence or absence of horizons as well as on similarities in chemical data.

Data Synthesis

Comparing and evaluating major chemical properties for groups of these Podzols determined by selection or cluster analysis allowed their assessment in relation to the factors of their formation, primarily in terms of climate and lithology of parent materials. It also enabled an assessment of their significance as soil taxa. Means and standard deviations for individual horizons and pedons were calculated in this study on a horizon or master horizon basis for the groups. It was necessary to calculate weighted means for each horizon type and for master horizons when more than one of each was present. Analytical values of individual horizons were weighted according to the thickness of the horizons.

RESULTS AND DISCUSSION

Results of Numerical Analysis

The CSSC (1978) Classification

The analysis based on the CSSC (1978) differentiae produced four major clusters, each having a different combination of horizons and chemical properties (Table 6). These four clusters can be identified on the basis of horizon sequences found to be unique for each group. From a numerical analysis viewpoint the clusters are thought to represent taxa at the first categorical level below the order level, but not necessarily comparable to the great group level.

As might be expected, Ferro-Humic Podzols (clusters A, B, and D) were separated from Humo-Ferric Podzols (cluster C); however, the three cluster groups produced for Ferro-Humic Podzols indicated a profound difference in both horizon sequences and chemical properties of the pedons included. Cluster B appears to have grouped pedons conforming to the central concept of the Ferro-Humic Podzol Great Group; cluster A consisted of pedons3lntegrading toward Folisols; and cluster D contained pedons integrading toward Humo-Ferric Podzols or Podzols with both Bhf and Bf horizons present in the soils.

Clusters B, C, and D were further subdivided (Table 7). The clusters produced for these groups represent the second categorical level below the order level, which could be related to the subgroup category. These clusters indicated that each major cluster was subdivided on the basis of a combination of presence or absence of H, Ah, and Ae horizons -- largely relinquished criteria of the present system.

To assure that the actual values for each horizon and cluster were meaningful and corresponded to the defined criteria, means and ranges were plotted for total C and pyrophosphate Fe and Al (Figure 2, 3, and 4). Pyrophosphate Fe and Al were quite variable within each horizon, effectively masking differences between horizons. This variability was greatest in the Bhf horizons, suggesting considerable differences in the nature and composition of this horizon.

TABLE 6. Horizon sequence of clusters based on the CSSC (1978)

Cluster	Horizon sequence					Number of pedons
A	LF	H	Ae	Bhf		11
B	LFH			Bhf		38
C	LFH				Bf	100
D	LFH			Bhf	Bf	28
					Total	177

TABLE 7. Horizon sequence of subdivided B, C, and D clusters of Table 6

Cluster	Horizon sequence					Number of pedons
A	LF	H	Ae	Bhf		11
B1	LFH			Bhf		14
B2	LFH	Ah		Bhf		18
B3	LFH			Bhf		6
C1	LFH		Ae			10
C2	LFH		(Ae)		Bf	61
C3	LFH	Ah	(Ae)		Bf	29
D1	LF	(H)		Bhf	Bf	8
D2	LFH		(Ae)	Bhf	Bf	20
					Total	177

The New Classification

The analysis based on the differentiae used in this study produced seven major clusters (Table 8). These clusters were identified according to their combinations of diagnostic podzolic B horizons. Cluster D predominantly contained those pedons with Bh* horizons; clusters A, B, and C consisted of pedons featuring a Bhf* horizon; clusters E and G contained pedons with a Bfh* horizon; and cluster F consisted of pedons featuring a Bf* horizon. The Humic* and Ferric* Podzol great groups corresponded to a single major cluster while more than one major cluster was recognized for the Ferro-Humic*

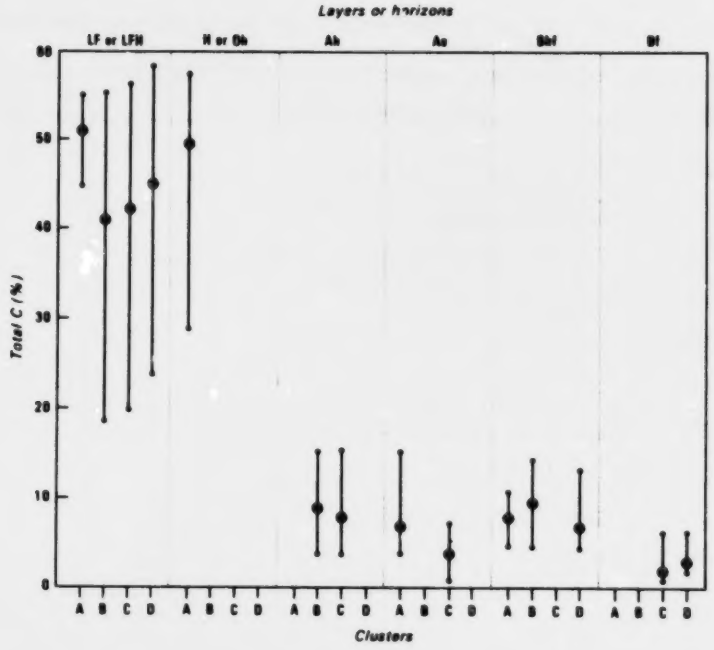

FIGURE 2. Mean and range values of total C for horizons and clusters based on the CSSC (1978) differentiae. The number of pedons in each cluster is given in Table 6.

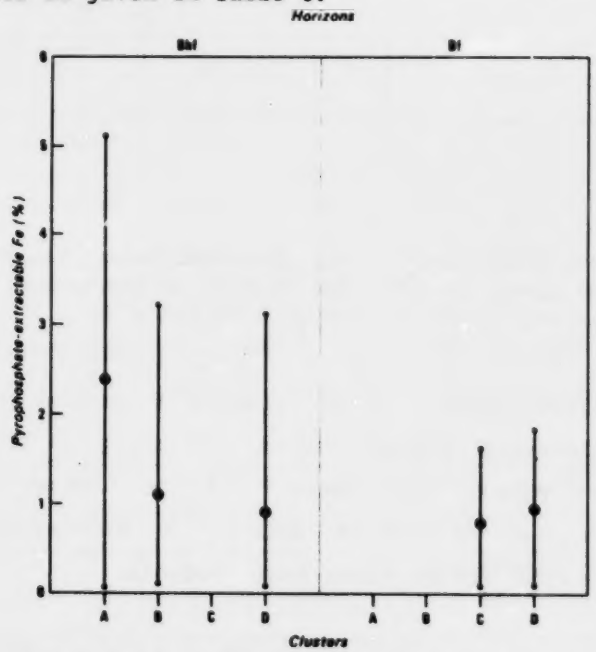

FIGURE 3. Mean and range values of pyrophosphate Fe for horizons and clusters based on the CSSC (1978) differentiae. The number of pedons in each cluster is given in Table 6.

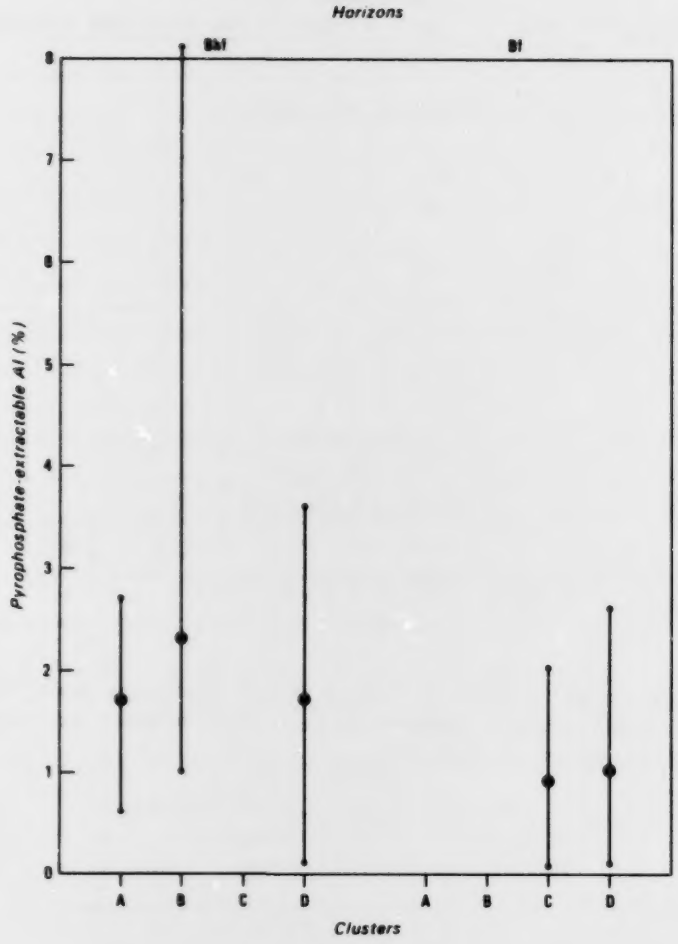

FIGURE 4. Mean and range value of pyrophosphate Al for horizons and clusters based on the CSSC (1978) differentiae. The number of pedons in each cluster is given in Table 6.

and Humo-Ferric* Podzol great groups. Cluster A grouped pedons integrading toward Folisols, cluster B grouped pedons conforming to the central concept of the Ferro-Humic* Podzol Great Group, and the cluster C grouped pedons integrading toward Humo-Ferric* Podzols - a clustering akin to that encountered for the CSSC (1978) Ferro-Humic Podzols.

Nearly all major clusters were further subdivided (Table 9). The clusters produced were characterized by unique horizon sequences including combinations of podzolic B horizons and H, Ah, and Ae horizons. Although

TABLE 8. Horizon sequence of clusters based on the new classification

Cluster	Horizon sequence						Number of pedons
A	LFH	H		Bhf*			7
B	LFH			Bhf*			21
C	LFH			Bhf*	Bfh*		16
D	LFH		Bh*				18
E	LFH				Bfh*		39
F	LFH					Bf*	43
G	LFH				Bfh*	Bf*	33
						Total	177

TABLE 9. Horizon sequence of subdivided B, C, D, E, F, and G clusters of Table 8

Cluster	Horizon sequence						Number of pedons
A	LF	H	(Ae)		Bhf*		7
B1	LFH	(Ah)			Bhf*		9
B2	LFH				Bhf*		7
B3	LFH				Bhf*	Bf*	5
C1	LF	(H)			Bhf*	Bfh*	11
C2	LFH		(Ae)		Bhf*	(Bfh*)	5
D1	LFH	(H)		Bh*	Bhf*		7
D2	LFH			Bh*		Bfh*	6
D3	LFH			Bh*			5
E1	LFH		Ae				10
E2	LFH		Ae			Bfh*	9
E3	LFH					Bfh*	13
E4	LFH	Ah				Bfh*	7
F1	LFH	Ah				Bf*	18
F2	LFH		(Ae)			Bf*	18
F3	LFH					Bf*	7
G1	LFH		Ae			Bfh* Bf*	13
G2	LFH					Bfh* Bf*	8
G3	LFH	(Ah)				Bfh* Bf*	12
						Total	177

the latter horizons are used as diagnostic at the subgroup level of the new classification, it is debatable whether each cluster, differentiated on the basis of various combinations of podzolic B horizons, should be interpreted as a new subgroup.

Means and ranges of total C and pyrophosphate Fe and Al for the podzolic B horizon as defined for the new classification were plotted (Figure 5, 6, and 7). These values decreased in the order of Bh*, Bhf*, Bfh* to Bf* horizons, the variation of organic C values being less than that of pyrophosphate Fe and Al.

Comparison of Groupings Created Through Cluster Analysis for the CSSC (1978) and New Classification

The four major groups separated using the CSSC (1978) criteria do not necessarily approximate the major groups separated using the new classification criteria (Tables 6 and 8). The distribution of pedons between the major clusters is given in Table 10.

TABLE 10. Distribution of pedons within the major clusters of the CSSC (1978) and new classification

Cluster [CSSC(1978)]	Number of pedons	Major clusters of the new classification						
		A	B	C	D	E	F	G
A	11	5		3	3			
B	38	1	17	4	11	5		
C	100			1		33	41	25
D	28		6	8	4		1	9
Total	177							

In the new classification the range in total C between the four recognized podzolic B horizons is defined to a level where the presence or absence of those horizons was of value in group separation. In the CSSC (1978) classification the range in total C within the two recognized podzolic B horizons was so great that separation placed a greater emphasis on the presence or absence of accessory horizons such as H, Ah, and Ae horizons.

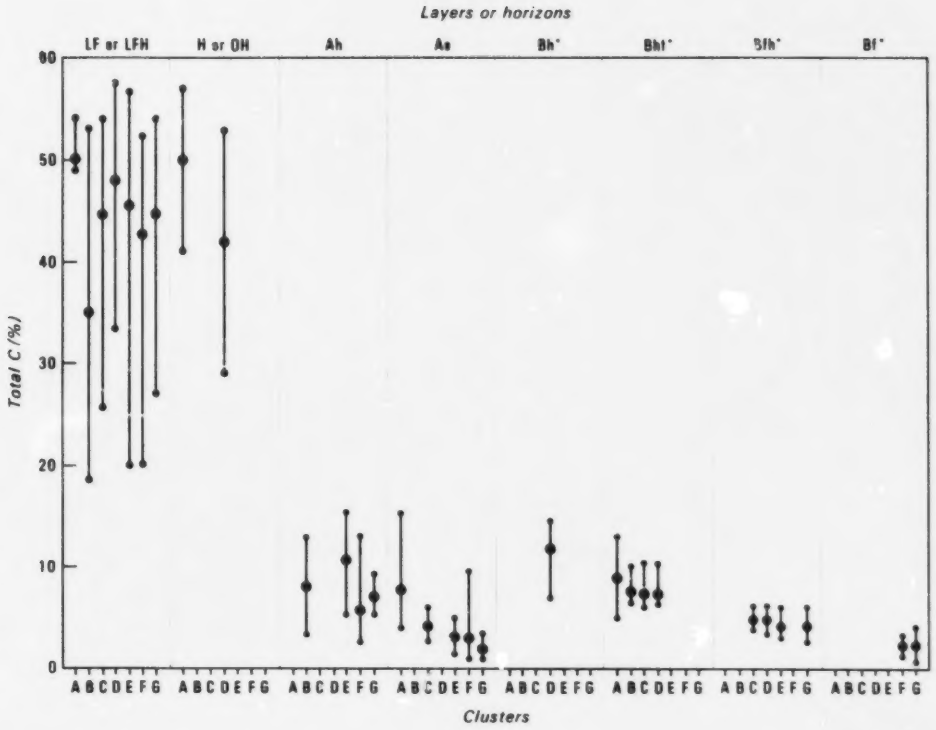

FIGURE 5. Mean and range values of total C for horizons and clusters based on the differentiae of this study. The number of pedons included in each cluster is given in Table 8.

The distribution of pedons within the subdivided clusters of the analyses for each of the classifications is given in Table 11. In the subdivided cluster A of the CSSC (1978) analysis all pedons had an H horizon. The separation appears to have been defined by the presence or absence of these horizons as total C ranged from 1.8 to 13.3% in the podzolic B horizons. Six of the seven pedons in cluster A of the new classification also had an H horizon although total C only ranged from 5.5 to 13.3%.

The pedons found in cluster B of the CSSC (1978) classification appeared to have no observable pattern. Total C ranged from 4.0 to 15.2% and the pedons had a relatively even distribution throughout six of the subdivided clusters of the new classification. No common accessory horizon was present.

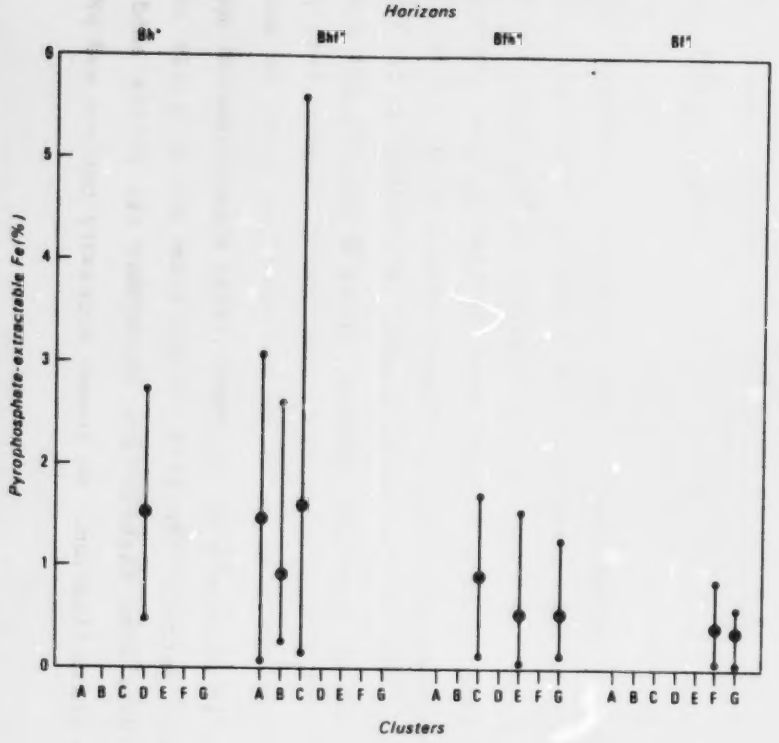

FIGURE 6. Mean and range values of pyrophosphate Fe for horizons and clusters based on the differentiae of this study. The number of pedons in each cluster is given in Table 8.

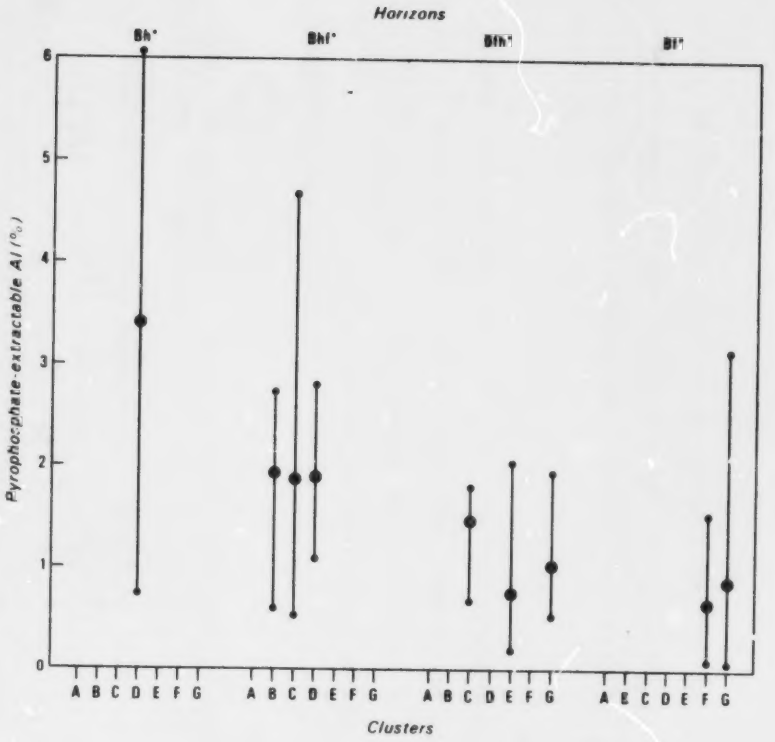

FIGURE 7 Mean and range values of pyrophosphate Al for horizons and clusters based on the differentiae of this study. The number of pedons in each cluster is given in Table 8.

TABLE 11. Distribution of pedons in the subdivided clusters of the CSSC (1978) and new classifications

Cluster [CSSC(1978)]	Number of pedons	Subdivided clusters of the new classification																	
		A	B1	B2	B3	C1	C2	D1	D2	D3	E1	E2	E3	E4	F1	F2	F3	G1	G2	G3
A	11	6				3		2												
B1	14		4			2		2	2			1	3							
B2	18	1	4	7		1	1	2					1	1						
B3	6		1						1	4										
C1	10										10									
C2	61											8	9		3	15	7	11	3	5
C3	29					1								6	14	2	1		2	3
D1	8					3		1	2						1					1
D2	20				6	1	4	1										2	3	3
Total	177																			

Cluster B2 of the CSSC (1978) classification was predominantly composed of pedons having Ah horizons (72%). All of the pedons in this cluster were from the University of B.C. Research Forest with an even distribution in the CWHa and CWHb subzones. Total C ranged from 5.1 to 12.4% and the pedons were divided between eight subdivided clusters of the new classification.

Cluster B3 of the CSSC (1978) classification closely approximated cluster D3 of the new classification. All pedons had a podzolic B horizon with total C of 9.5% or higher with all pedons but one having a Bh* horizon greater than 10 cm thick. All pedons grouped in this cluster occurred in the University of B.C. Research Forest in both the CWHa and CWHb subzones.

Cluster C1 of the CSSC (1978) classification was found to be identical to cluster E1 of the new classification. These pedons were found throughout the study area, and were characterized by an LFH layer over an Ae horizon having a lithic contact.

The pedons found in cluster C2 of the CSSC (1978) classification were distributed through eight cluster groups of the new classification. In general, they were characterized by a low organic carbon content (usually less than 4.0%) with 41% having Ah or Ae horizons. These pedons were found in all subzones studied although they were predominant in the CWHa Subzone. The new classification was able to separate the large number of pedons in this group to more specific groups. Fifteen of the 18 pedons of cluster F2 were grouped in this cluster. These pedons were characterized by the presence of a Bf* horizon, often with an Ae horizon. All of the pedons grouped in cluster F3 of the new classification were also included in this cluster. These pedons all had diagnostic Bf* horizons. These pedons would likely have been separated at a more specific level of the CSSC (1978) classification as they were grouped adjacent to one another in this cluster. Eight out of nine and 11 out of 13 pedons of clusters E2 and G1 of the new classification were grouped in this cluster group, respectively. The analysis using the new classification criteria separated these groups on the basis of unique horizon sequences; LFH, Ae, Bfh*, Bf* for cluster G1, and LFH, Ae, Bfh*, for cluster E2.

The pedons in cluster C3 of the CSSC (1978) classification were distributed throughout eight cluster groups of the new classification; however, they primarily represent two cluster groups of the new classification, clusters F1 and E4. Total carbon ranged from 1.5 to 9.5%, although it was generally less than 4.0%. The separation of this group appears to be based on the presence of an Ah horizon. Twenty-eight of 29 pedons had an Ah (or Ahe) horizon. The analysis using the new classification criteria further separated this group into clusters having unique horizon sequences such as LFH, Ah, Bf* (cluster F1) and LFH, Ah, Bfh* (cluster E4). The pedons grouped in this cluster occurred primarily in the CWHa Subzone, although they were also found in the CWHb Subzone (9 pedons).

Cluster D of the CSSC (1978) classification is composed of pedons having a range in total C of 6.0 to 12.6%. These pedons were all located in the CWHb subzone and in the CWHb/d ecotone. The pedons grouped in this cluster were found in five clusters created using the new classification criteria. No particular horizon sequence is dominant although one-half of the pedons had an H horizon and most pedons had decreasing organic matter content with depth.

The pedons in cluster group D2 of the CSSC (1978) classification were distributed across eight cluster groups of the new classification. Cluster groups B3 and C2 of the new classification were included in their entirety. Most of these pedons had intermediate amounts of organic matter in their podzolic B horizons with total C normally between 5.5 and 8.5%. The separation using the CSSC (1978) criteria was unable to effectively subdivide this cluster due to insufficient discrimination of podzolic B horizons based on total C. The separation based on the new classification criteria was able to classify the pedons in this cluster according to unique horizon sequences such as LFH, Bhf*, Bf* and LFH, Bhf*, Bfh*, Bf* for new classification cluster groups B3 and C2, respectively. All but one of these pedons occurred in the University of B.C. Research Forest.

In summary, cluster analyses based on both the CSSC (1978) and the new classification differentiae was carried out for the studied Podzols using

multi-horizon and multi-parameter data. Both analyses used the presence and/or absence of diagnostic horizons and differences in total C for separation of the cluster groups. The analysis that utilized the new classification differentiae created 19 subdivisions while the analysis that utilized the CSSC (1978) differentiae created nine subdivisions of the major clusters. The new classification differentiae allowed more specific separation due to the more refined division of diagnostic podzolic B horizons based on the content of total C. This increased the number of specific horizon sequences which could be used for classification.

Due to the broad range of total C values used for classification in the present Canadian system, the separation was often based on the presence and/or absence of accessory horizons such as H, Ah or Ahe, and Ae, often neglecting the use of secondary podzolic B horizons which are not a part of the current classification.

Secondary chemical characteristics, such as pH, total N, C/N ratio, cation exchange capacity, were not used in either of the separations tested through cluster analysis. However, these soil properties are known to be correlated with organic matter and showed similar trends between the classification systems as described earlier, with greater variation found for the CSSC (1978) clusters than for those separated using the new classification differentiae. This trend can be observed in Figures 8 and 9 showing mean and range values for total N.

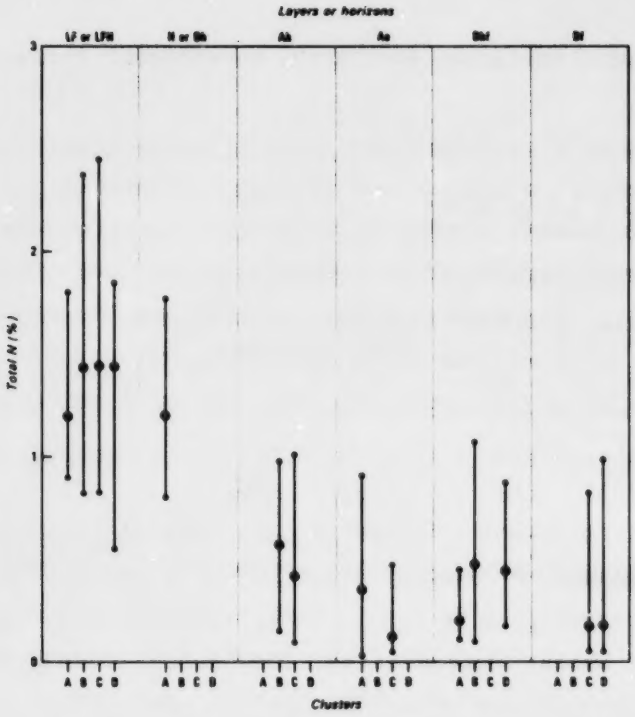

FIGURE 8. Mean and range values of total N for horizons and clusters based on the CSSC (1978) differentiae. The number of pedons in each cluster is given in Table 6.

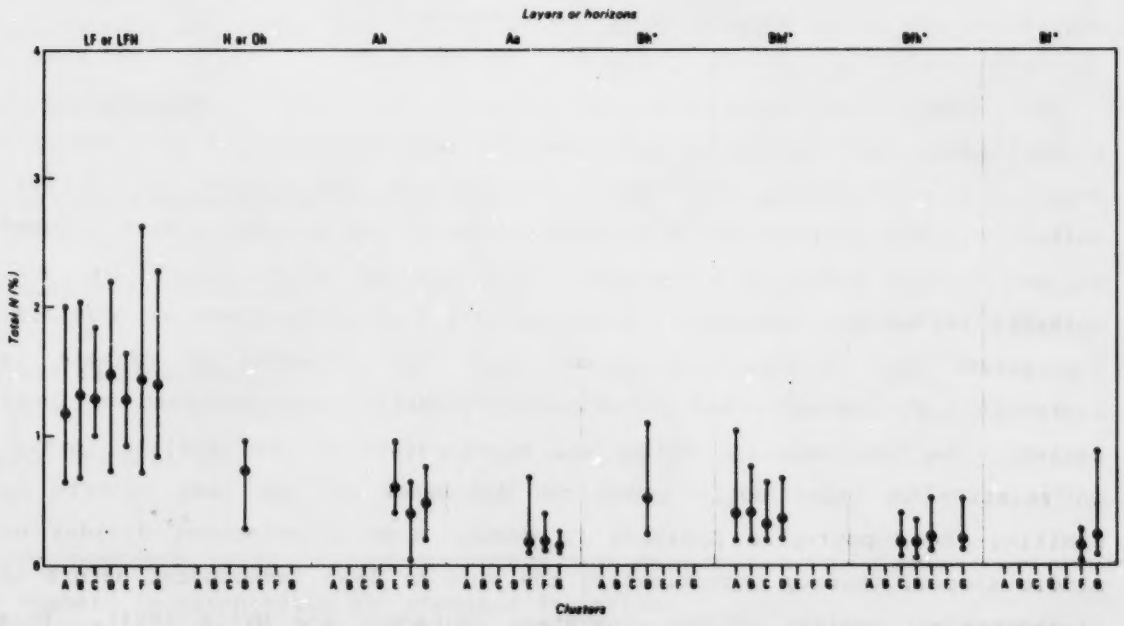

FIGURE 9. Mean and range values of total N for horizons and clusters based on the differentiae of this study. The number of pedons in each cluster is given in Table 8.

Climatic Variation within the Mesothermal Podzols

The sampled Podzols were confined to a climatic gradient extending from the driest and warmest to coolest and wettest mesothermal climate of the CWH Zone in coastal southwestern British Columbia. Applying the biogeoclimatic level of ecosystem classification, this gradient was divided into four segments (Table 12). The MacMillan Park Podzols were in the ecotone between the CDFb and CWHa subzones; the CWHb2 Variant represents a montane variation of a perhumid mesothermal climate characterized by a shorter growing season and higher snowfall.

The climatic gradient indicates a general increase of those characteristics related to precipitation and a general decrease for those related to temperature (Table 12). While there are notable differences between drier and wetter subzones, the difference between the variants of the CWHa Subzone or between the CWHb2 Variant and CWHb/d ecotone is less pronounced. The summer precipitation patterns expressed by mean precipitation April to September, mean precipitation of the driest month, and mean temperature of the warmest month appear to differentiate between both drier and wetter variations of the gradient.

To assess the influence of climate on podzol genesis, each biogeoclimatic unit on the climatic gradient was characterized by a group of zonal, i.e., non-lithic, moderately well drained, and glacial till-derived soils. Climate, vegetation, and lithology of parent materials were allowed to vary, while other site factors, in particular those controlling soil moisture regime and topographic position were kept as constant as possible. The intent was to select soils on which the influence of climate is expressed most strongly, i.e., the climate remains least modified by local relief. The soil moisture regime was standardized to intermediate (mesic) in relation to other soils under the influence of the same climate by limiting the topographic position to gently sloping watershed divides or middle slopes, thereby approximating the more or less independent nature of biogeochemical cycling of the ecosystems (Sukachev and Dylis 1964). Thus the selected groups represent a mesic vegetation and soil climosequence, featuring a contrasting till lithology for both the drier and wetter

TABLE 12. Means and standard deviations[1] of climatic data for biogeoclimatic units in the study area

Biogeoclimatic subzone / Biogeoclimatic variant	CDFb	CWHa		CWHb	CWHb/d
		CWHa1	CWHa2	CWHb2	
Number of climatic stations	19	3	19	12	5
Study area	MacMillan Park		UBC Research Forest		Koprino
Climate (Koppen/Trewartha)	wetter Csb	drier Cfb	drier Cfb	wetter Cfb-Cfc	wetter Cfb
Mean annual precipitation (mm)	1304 (260.0)	1940 (399.9)	1742 (286.4)	2236 (620.6)	2125 (682.7)
Mean precipitation April - September (mm)	300 (45.3)	386 (45.6)	483 (65.8)	615 (145)	545 (113.8)
Mean precipitation of the driest month (mm)	32 (6.2)	36 (2.9)	49 (6.9)	62 (13)	56 (6.0)
Mean annual temperature (^{o}C)	9.0 (0.5)	8.1 (0.7)	8.9 (1.4)	5.6 (0.6)	8.6 (0.6)
Mean temperature of the warmest month (^{o}C)	16.9 (0.58)	16.2 (1.16)	16.8 (1.33)	13.5 (0.58)	14.6 (1.08)
Accumulated degree days over $5^{o}C$	1882 (102.9)	1733 (115.1)	1933 (253.0)	1426 (204.4)	1569 (184.9)
Potential evapotranspiration (mm)	424 (54.7)	435 (115.8)	404 (48.8)	334 (28.3)	346 (39.4)
Actual evapotranspiration (mm)	341 (31.0)	371 (21.1)	396 (43.9)	334 (28.3)	346 (39.4)
Water surplus (mm)	961 (247)	1569 (330.1)	1345 (272.3)	1902 (622.8)	1779 (656.0)
Water deficit (mm)	82 (48)	63 (42)	7 (10)	0 (0)	0 (0)

[1] Numbers in parenthesis are standard deviations.

segments of the gradient. Basaltic and andesitic tills were dominant in the Cameron River Valley (CWHa1) and Koprino River Watershed (CWHb/d) while quarzdiorite tills were dominant in the University of B.C. Research Forest (CWHa2 and CWHb2).

A comparison of mesic Podzols with respect to mean values for the selected properties indicated both similarities and differences, apparently related to the effects of climate or combined effects of climate and lithology of parent materials (Tables 1, 2, 3, and 4, Appendix). The following discussion is consistent with reports from the same or other regions of coniferous vegetation and humid climate.

Surface Organic Layers

Surface organic layers were between 7 and 20 cm thick with the total thickness and the thickness of H horizons increasing from the drier to wetter subzones, the latter variation being responsible for differences in humus form classification (Table 13). White and yellow fungal mycelia and fragments of decaying coniferous wood were present in significant amounts in all layers. The layers were more friable in the drier than in the wetter subzones, where they were more compacted and matted by mycelia and roots. Lower pH and exchangeable Ca levels and higher C/N ratios were characteristic for layers of the wetter subzones reflecting the trend of decreasing temperature and increasing moisture. Exchange properties in relation to climate did not appear to be markedly different, possibly obscured by differences in litter materials and horizonation of the LFH layer among the sites. The ratio of exchangeable Ca/Mg, however, differed markedly between the drier and wetter subzones. This was consistent with previous reports (Klinka and Lowe 1975, 1976a, and 1976b; Lowe and Klinka 1981) for the CWH Zone in which decreasing pH was associated with decreasing ratio of exchangeable Ca/Mg. In the wetter subzones exchangeable Ca relative to Mg was depleted to a much greater extent than in the drier subzones.

The most striking aspect, in regard to organic constituents, was the difference in the content of humic acid (HA) and ratio of humic/fulvic acid

TABLE 13. Weighted means and standard deviations[1] of selected chemical properties for the surface organic layer of mesic Podzols

Biogeoclimatic unit Number of layers	CDFb/CWHa1 5	CWHa2 6	CWHb3 9	CWHb/d 10
Humus form	Hemimor	Hemihumimor	Humimor	Humimor
Thickness (cm)	7.4 (1.51)	11.1 (10.9)	13.6 (3.0)	20.2 (11.1)
pH ($CaCl_2$)	4.1 (0.31)	3.4 (0.19)	3.2 (0.15)	3.2 (1.4)
C/N	46.3 (4.40)	34.6 (3.00)	42.5 (9.01)	46.3 (12.1)
Exchangeable Ca (meq/100g)	22.0 (16.1)	14.3 (2.21)	9.28 (3.86)	11.60 (4.91)
Exchangeable Mg (meq/100g)	3.45 (0.43)	2.54 (0.56)	2.66 (0.70)	8.02 (4.14)
Exchangeable Ca/Mg	5.2 (4.1)	6.1 (1.4)	4.1 (1.3)	1.3 (0.97)
CEC (meq/100g)	70.4 (9.09)	180.7 (56.2)	114.1 (16.1)	116.3 (35.5)
BS (%)	43.1 (21.1)	11.6 (5.74)	13.8 (3.89)	15.8 (15.1)
Humic acid (HA) (% of total C)[2]	14.1 (4.33)	27.5 (3.18)	28.2 (2.51)	34.4 (22.4)
Fulvic acid (FA) (% of total C)[2]	13.1 (3.05)	24.5 (2.09)	14.2 (1.77)	10.9 (3.07)
CHA/CFA[2]	1.1 (0.4)	1.1 (0.2)	2.0 (0.3)	4.1 (4.9)
$E^{1\%}_{400nm}$ of HA (E4)[2]	78 (15)	32 (16)	42 (12)	62 (16)
E4/E6 of HA[2]	7.1 (1.1)	6.3 (1.1)	6.1 (0.9)	11.7 (5.1)

[1] Numbers in parenthesis are standard deviations.

[2] Source is Lowe and Klinka (1981) and Klinka and Lowe (1976a and b). The values were derived from five composite samples of the LFH layer of pedons also included in this study.

(CHA/CFA). Mean values of both properties increased from drier to wetter subzones, suggesting a greater accumulation of HA in wetter climate systems. The production of FA varied within a much narrower range, hence the CHA/CFA ratio was largely controlled by the level of HA. Optical properties of humic acids - low extinction coefficients ($E^{1\%}_{400nm}$) and high extinction ratios (E4/E6) - were in the range characteristic for mesic Mors in the CWH Zone reported by Lowe and Klinka (1981). Higher values of the ($E^{1\%}_{400nm}$) for the CWHa1 and CWHb/d than for the CWHa2 and CWHb2 biogeoclimatic units reflected the darker colour of HA, although the HA had a low degree of maturation as indicated by the higher E4/E6 values.

Lowe and Klinka (1981) have shown that the thickest accumulation of the LFH layer was characterized by the highest accumulation of least mature (least oxidized) HA. These accumulations only occurred in wet and acid systems with relatively low nitrogen levels (wide C/N ratios) where conditions might limit the rate of HA degradation but increase the rate of HA synthesis by favouring a high biological (mainly mycogenous) activity, largely responsible for the decomposition of plant debris and concurrent Mor formation.

Podzolic B Horizons

The increasing accumulation of organic matter in the LFH layer along the climatic gradient was paralleled in the B horizon (Table 14). Consistently, the wetter subzone Podzols had greater amounts of total C than the corresponding drier subzone Podzols. Differences between the soils of the CWHa1 and CWHa2 variants were negligible. However, the CWHb/d Podzols had nearly twice as much total C as the CWHb2 Podzols. Therefore, it would appear that increments in the content of organic matter in podzolic B horizons are closely allied with biogeoclimatic subzones. This could be expected because the main purpose of these taxa is to provide climatically uniform classes of ecosystems.

To substantiate the adopted class limits of total C for the podzolic B horizons diagnostic for the new great groups, 95 percent confidence limits

TABLE 14. Weighted means and standard deviations[1] of selected chemical properties for the master B horizon of mesic Podzols

Biogeoclimatic unit Number of horizons	CDFb/CWHa1 10	CWHa2 16	CWHb2 12	CWHb/d 11
pH ($CaCl_2$)	4.5 (0.20)	4.7 (0.20)	4.4 (0.4)	4.1 (0.4)
Total C (%)	2.04 (0.93)	2.03 (1.89)	3.38 (1.51)	6.23 (2.85)
Total N (%)	0.08 (0.03)	0.12 (0.09)	0.16 (0.10)	0.20 (0.11)
C/N	24.0 (6.04)	16.0 (3.04)	31.5 (23.0)	31.3 (3.69)
Exchangeable Ca (meq/100g)	1.25 (0.47)	0.23 (0.19)	0.12 (0.07)	0.80 (0.61)
Exchangeable Mg (meq/100g)	0.28 (0.11)	0.03 (0.01)	0.05 (0.02)	0.32 (0.23)
Exchangeable Ca/Mg	4.3 (0.59)	6.6 (2.4)	2.7 (2.3)	5.6 (8.1)
CEC (meq/100g)	16.7 (4.92)	21.5 (12.1)	27.6 (9.43)	39.5 (13.8)
BS (%)	10.9 (5.14)	2.1 (1.4)	1.3 (0.80)	3.4 (1.8)
Oxalate Fe (%)	1.34 (0.41)	0.56 (0.45)	1.01 (0.44)	2.44 (1.32)
Oxalate Al (%)	1.24 (0.56)	1.65 (1.04)	1.94 (1.07)	2.41 (1.40)
Pyrophosphate Fe (%)	0.40 (0.19)	0.19 (0.13)	0.42 (0.37)	1.76 (1.15)
Pyrophosphate Al (%)	0.63 (0.16)	0.68 (0.44)	0.94 (0.66)	1.47 (0.66)

[1] Numbers in parenthesis are standard deviations.

for the master B horizons of mesic Podzols are presented in Table 15. The rationale of selecting mesic Podzols for this purpose reflected the desire to relate the classification at the great group level to regional climate. Comparing the upper limits of the master B horizons, it is apparent that the adopted 3, 6, and 10 percent levels as differentiating between the Bf* and Bfh*, Bfh* and Bhf*, and Bhf* and Bh*, respectively, correspond reasonably well to natural variation of total C in mesic Podzols. The large standard deviation for the CWHa2 Variant was due to one Bhf* and one Bfh* horizon present in the collection of six mesic Podzols. When these rather unusual horizons are excluded, the upper limit of total C for the CWHa2 Podzols is 2.59%. The class limit of 5% has been used by both NSSC (1970) and (CSSC 1978) whereas that of 6% was selected by the Soil Survey Staff (1975) to differentiate between low and high organic matter podzolic B horizons; the 10% class limit was used by NSSC (1970) to define the Bhf horizons. The upper limits for total C of approximatley 3% for the Bf* horizon, 3-6% for the Bfh* horizon, 10% for Bhf* horizon, and greater than 10% for the Bh* horizon were used to define the class limits of the podzolic great groups of this study as presented in Table 3.

Acidity showed a decreasing trend along the climatic gradient, whereas values of properties closely related to organic matter, such as nitrogen and sulfur, increased. A significant decrease of available phosphorus from the drier to wetter subzone of the CWH Zone was reported by Lewis (1976). Appreciable differences in cation exchange capacity between the subzones were attributed to climatically induced differences in total carbon and sesquioxide content.

Consistent with other reports, exchangeable Ca and the ratio of exchangeable Ca/Mg decreased in the wetter subzone Podzols; however, this trend was obscured in the present data, likely because of differences in parent material mineralogy. Thus, regardless of climate, the levels of exchangeable Ca and Mg were higher in the Podzols formed from base-rich materials in the CWHa1 variant and CWHb/d ecotone than in those which have formed from base-poor, quartzdiorite materials in the CWHa2 and CWHb2 variants.

TABLE 15. 95 percent confidence limits for total C in the master B horizons of mesic Podzols

Biogeoclimatic unit	Number of horizons/ pedons	Classification of the master B horizon	Total C		
			$\bar{x} - 2s$	$\bar{x}$	$\bar{x} + 2s$
CDFb/CWHa1	10/5	Bf*	0.51	2.04	3.57
CWHa2	16/6	Bf*	0.00	2.03	5.15
CWHb2	12/9	Bfh*	0.89	3.38	5.87
CWHb/d	11/6	Bhf*	1.53	6.23	10.93

The distribution pattern described for total carbon and exchangeable cations was also similar to the pattern observed for extractable sesquioxides. Both oxalate and pyrophosphate Fe and Al effectively separated the drier and wetter subzone Podzols with the CWHb/d Podzols containing twice as much as the CWHb2 Podzols (Table 16).

The dichotomy of sesquioxide contents (particularly of Fe) was apparently related to differences in mineralogy of parent materials which, as in the case of exchangeable Ca, obscured the effect of climate. Thus, the levels of sesquioxides were markedly higher in the CWHa1 and CWHb/d Podzols formed from basaltic tills than in the CWHa2 and CWHb2 Podzols which have formed from quartzdiorite tills. Furthermore, this dichotomy was accompanied by differences in the frequency and thickness of albic horizons which were absent or less frequent and thinner in the former Podzols and more common and thicker in the latter Podzols (Table 16). This observation conforms to Lewis' (1976) finding advancing the following relationship: in mesothermal Podzols formation of albic horizons is confined to well-sorted, coarse, siliceous sands, where the content of bases, iron and even silicate is low. When quartz is lacking in the parent rock the Ae horizons are absent or incipient. Since quartz-rich materials tend to be iron-poor, it is expected that, in a given biogeoclimatic system, Ae/B (albic)-Podzols will have weaker B horizons than Ae-less (spodic) Podzols as measured by their sesquioxide content. This relationship is detectable in our data, where, in climatically equivalent environments, Podzols with the strongest

TABLE 16. Frequency and thickness of albic horizons and sesquioxide contents in the master podzolic B horizon of spodic and albic mesic Podzols in relation to climate and parent materials

Climate (Köppen/Trewartha)	drier Cfb		wetter Cfb	
Biogeoclimatic subzone	CWHa		CWHb	CWHb/d
Biogeoclimatic variant	CWHa1	CWHa2	CWHb2	
Parent till	basaltic	granitic	granitic	basaltic
Podzol	spodic*	albic*	albic*	spodic*
Number of pedons	10	16	12	11
Albic horizon:				
Frequency (%)	0	25	83	27
Thickness (cm)	0	6.2	13.9	2.7
Master podzolic B horizon:				
Oxalate Fe and Al	2.58	2.21	2.95	4.85
Pyrophosphate Fe and Al	1.03	0.87	1.36	3.23

albic horizons exhibited the least sesquioxidic B horizons whereas those with the most sesquioxidic B horizons had albic horizons that were weakly expressed or absent. The former group of soils was characteristic for quartzdiorite tills, whereas the latter was typical for basaltic tills.

In summary, a comparison of selected properties of mesic Podzols representing a climosequence of the CWH Zone indicated that soil formation in all three subzones is governed by similar pedogenic processes although the soils varied in the expression of all properties examined. In the driest and warmest mesothermal climate, Podzols were found to integrade into Brunisols; this was interpreted as the onset of a climatically controlled formation of Podzols. In the coolest and wettest mesothermal climate, Podzols that featured incipient gleying were the dominant soils in the majority of ecosystems.

Interpretation of the climosequence suggested that the groupings at the level of biogeoclimatic subzone were useful in assessing the effect of climate on podzol formation. As expected, a number of properties were

directly or indirectly affected by climate: however, the mineralogy of parent materials influenced most properties, notably the content of extractable Fe, suggesting that the effect of the parent material factor is different in different biogeoclimatic subzones. The distribution of organic matter in soils and the content of extractable sesquioxides in mesic Podzols were the properties most affected by climate. If accumulation of acid, humified materials in the LFH layer and organic matter and sesquioxides in the B horizon are considered to be the main characteristics of Podzols, then podzolization intensified with increasing humidity and decreasing temperature of regional climate.

Characterization and Classification of Mesothermal Podzols

In general, a mesothermal Podzol is characterized by a thick Mor humus form, an infrequent and thin umbric or albic horizon, and a sequence of yellowish brown to reddish brown, sandy to loamy-skeletal, weakly structured podzolic B horizons. Transition to the underlying, relatively unweathered, basal till or bedrock is always abrupt. The typical chemical characteristics are high acidity and pH-dependent cation exchange capacity, both decreasing with depth; low content of bases and large amounts of organic matter and sesquioxides, occurring to considerable depth. Depending on regional climate, soil moisture, and nutrient regime, the associated forest communities vary in composition, structure, and productivity.

Four great groups, excluding the (Humic) Humus* Podzol Great Group, were recognized and tested for the Podzols in the CWH Zone (Table 17). These great groups are further subdivided into four subgroups differentiated by the presence or absence of surface or subsurface non-podzolic B horizons. Both great groups and subgroups are discussed in terms of horizon sequences and some morphological and chemical characteristics including crude vegetation-environment relationships to support the taxonomic and interpretive significance of the new taxa.

Surface Organic Layers

The thick (8 to 18 cm) surface organic layer consisted typically of L, F, and H horizons, with a subsurface (less than 40 cm thick) H or Oh horizon occurring on imperfectly to poorly drained sites in the wetter subzones of the CWH Zone (Table 18). Although the humus forms of the studied soils varied, the mycelial Mors featuring a high proportion of root residues and decaying wood materials were most common. The diagnostic F horizon had a matted, plate-like fabric interwoven by fungal hyphae. An organic layer, comprised almost entirely of gray fungal mycelia was occasionally found in Mors located in the CWHal Variant. The H horizon had either a reddish brown colour, indicative of large amounts of woody materials in the forest floor, or a very dark gray colour (and coarse, block-like structure in the wetter

TABLE 17. Synopsis of new great groups and subgroups

Cluster	New great group	New subgroup			Sequence of podsolic B horizons				
D1	Humic*	Folisolic*				Bh*	Bhf*		
D2					Spodic*	Bh*		Bfh*	
D3					Spodic*	Bh*			
A	Ferro-Humic*	Folisolic*		(Albic*)			Bhf*		
B1			(Umbric*)				Bhf*		
B2					Spodic*		Bhf*		
B3					Spodic*		Bhf*		Bf*
C1		(Folisolic*)					Bhf*	Bfh*	
C2				Albic*			Bhf*	(Bfh*)	
E1	Humo-Ferric*			Albic*					
E2				Albic*				Bfh*	
E3					Spodic*			Bfh*	
E4			Umbric*					Bfh*	
G1				Albic*				Bfh*	Bf*
G2					Spodic*			Bfh*	Bf*
G3			(Umbric*)					Bfh*	Bf*
F1	Ferric*		Umbric*						Bf*
F2				(Albic*)					Bf*
F3					Spodic*				Bf*

TABLE 18. Weighted means and standard deviations[1] of some chemical properties of the surface organic layer for new great groups

Tentative great group	Number of layers/ pedons	Thickness (cm)	pH ($CaCl_2$)	Total C (%)	Total N (%)	C/N	Exchangeable cations					
							Ca	Mg (meq/100g)	Na	K	CEC (meq/100g)	BS (%)
Humic*	31/22	16.8 (2.84)	3.6 (0.66)	44.8 (8.51)	1.24 (0.40)	42.9 (20.1)	9.01 (13.4)	4.95 (5.00)	0.73 (0.52)	1.13 (0.57)	118.8 (26.9)	15.2 (12.7)
Ferro-Humic*	54/40	17.8 (9.24)	3.4 (0.63)	43.3 (12.1)	1.28 (0.37)	37.6 (14.6)	11.7 (9.49)	5.91 (5.17)	0.69 (0.43)	1.23 (0.73)	112.0 (31.6)	16.5 (12.5)
Humo-Ferric*	65/65	10.0 (7.2)	3.5 (0.54)	45.3 (9.36)	1.36 (0.33)	34.6 (9.14)	12.6 (10.6)	3.04 (1.99)	0.77 (0.49)	2.23 (1.14)	122.7 (36.3)	16.7 (12.7)
Ferric*	50/50	8.4 (5.2)	3.5 (0.92)	43.3 (8.82)	1.19 (0.37)	39.0 (11.9)	19.8 (12.0)	3.70 (1.74)	0.63 (0.47)	2.25 (1.33)	99.1 (43.4)	30.5 (21.4)

[1] Numbers in parenthesis are standard deviations.

subzones), indicative of very fine materials with a distinct greasy tactility. Roots were abundant, in fact at a maximum in F and H horizons.

Mor humus forms generally had relatively high acidity, C/N ratio and pH dependent cation exchange capacity. However, in comparison to other horizons, most of the exchangeable bases in these soils appear to reside in the surface organic layers. This applies also to other macro- or micronutrients commonly associated with organic matter, namely nitrogen, sulphur, and phosphorus. The significance of the surface organic layer of Podzols as a storage of potentially available nutrients has been emphasized by many workers; however, the problems involved in the mobilization of this potential and, in fact, sound 'humus management' have not yet been resolved.

Podzolic B Horizons

The master podzolic B horizons dominated the solum of mesothermal Podzols. Common morphological features were those described by Lewis (1976) as follows:

1. a considerable variation in distribution of organic matter in the upper horizons resulting from pedoturbation, colluvial processes, and in situ decomposition of old roots;
2. a general decrease in the content of organic matter with depth; and
3. mottled, duller colours of the lower horizons, indicative of incipient gleying.

Incipiently gleyed lower horizons were common to seepage sites. Under these conditions these lower horizons frequently displayed an increased content of organic matter and exchangeable cations (Klinka 1976). Chemical analysis of the master podzolic B horizon for the new great groups is presented in Table 19. A comparison of the values for the horizons revealed several common features and expected relationships. Acidity is nearly one pH unit higher than for the surface organic layers, slightly increasing from Humic* to Ferro-Humic*, Humo-Ferric*, and to Ferric* Podzols. Total C decreased gradually along the same sequence reflecting the chosen criteria for the diagnostic horizons. Values for total N, C/N ratio, cation exchange

TABLE 19. Weighted means and standard deviations[1] of some chemical properties of the master podzolic B horizons for new great groups

Tentative great group	Number of horizons/ pedons	pH ($CaCl_2$)	Total C (%)	Total N (%)	C/N	Exchangeable cations				CEC (meq/100g)	BS (%)	Oxalate-extractable		Pyrophosphate-extractable	
						Ca	Mg	Na	K			Fe	Al	Fe	Al
						(meq/100g)						(%)			
Humic* Podsols	37/22	4.5 (0.41)	9.56 (3.95)	0.45 (0.26)	25.0 (11.3)	1.83 (4.71)	0.29 (0.50)	0.23 (0.19)	0.22 (0.21)	60.8 (30.2)	3.7 (3.6)	2.06 (1.52)	4.43 (7.09)	1.10 (0.86)	2.67 (1.60)
Ferro-Humic* Podsols	87/40	4.5 (0.37)	6.15 (2.25)	0.30 (0.14)	21.6 (6.47)	1.21 (1.60)	0.26 (0.58)	0.12 (0.07)	0.15 (0.21)	40.8 (11.0)	4.5 (5.3)	1.60 (1.06)	3.07 (1.48)	1.07 (0.99)	1.73 (0.81)
Humo-Ferric* Podsols	98/65	4.6 (0.37)	3.22 (1.60)	0.22 (0.15)	18.4 (15.0)	0.61 (0.75)	0.20 (0.62)	0.10 (0.10)	0.11 (0.08)	28.8 (11.2)	3.8 (4.3)	0.85 (0.55)	2.09 (1.09)	0.36 (0.49)	0.95 (0.45)
Ferric* Podsols	120/50	4.8 (0.40)	1.71 (1.00)	0.12 (0.14)	17.5 (8.47)	1.56 (2.86)	0.29 (0.36)	0.07 (0.04)	0.09 (0.07)	18.6 (9.64)	13.2 (17.2)	0.83 (0.50)	1.30 (0.79)	0.26 (0.17)	0.61 (0.35)

[1] Numbers in parenthesis are standard deviations.

capacity, and extractable sesquioxides show a similar trend. Lewis (1976) showed that a combination of high amounts of both organic matter and sesquioxides engenders a large pH-dependent cation exchange capacity in podzolic B horizons. Generally, low values for base saturation determined by the ammonium acetate (pH 7.0) method are deceiving when applied to acidic soils; however, the actual values for exchangeable cations, particularly for calcium, are consistently low. A considerable portion of variation in nutrient status was attributed by Lewis (1976) to the effects of regional climate and lithology of parent materials. He concluded that the combination of humid climate, accumulation of organic matter, and intensive weathering compensates for losses of materials, thereby maintaining the high productivity potential of these Podzols for forest crops.

The sesquioxide content yielded by both extractions showed the same trend as that for total carbon, indicating that accumulation of organic matter in the master podzolic B horizon and the build-up of sesquioxides, whether by in situ weathering or by illuviation, are closely related.

When mean values were examined, the content of oxalate-extractable sesquioxides was found to be 1.3 to 2.7% higher than that yielded by the

pyrophosphate extraction. Aluminum was the dominant sesquioxide in both extractions, accounting for 61.0 to 71.1% of total oxalate-extractable sesquioxides and 61.8 to 72.5% of total pyrophosphate-extractable sesquioxides. It would appear that these mesothermal podzolic horizons are more closely aligned to spodic horizons of Soil Survey Staff (1975) which are defined by the accumulation of amorphous mixtures of organic matter and aluminum, with or without iron. In the Canadian system (CSSC 1978) a podzolic B horizon is defined as one in which the dominant accumulation product is amorphous material composed mainly of humified organic matter combined in varying degrees with aluminum and iron. This preponderance of aluminum over iron was considered by some workers to be the major characteristic of sesquioxidic podzolic B horizons (Russell 1978).

Lewis (1976) explained the large content of sesquioxides in mesothermal Podzols by the predomination of intensive in situ weathering over translocation of organically complexed sesquioxides into podzolic B horizons. In situ-weathering, that involves great losses of bases and silica to drainage waters, leads to negative enrichment of the residual materials in the podzolic B horizons with iron and aluminum.

The pyrophosphate to oxalate Fe and Al ratio indicated a moderate preponderance of pyrophosphate Fe and Al for Humic* (0.58) and Ferro-Humic* (0.60) Podzols over Humo-Ferric* and Ferric* Podzols (0.48 and 0.40, respectively). As discussed further in the text, the former great groups are characteristic for the wetter subzones whereas the latter great groups are characteristic for the drier subzones of the CWH Zone. Interpreting the nature of the two extractions (Bascomb 1968, McKeague et al. 1971), this separation tends to suggest a more intensive translocation of organically complexed sesquioxides in Humic* and Ferro-Humic* than in Humo-Ferric* and Ferric* Podzols.

It appears that apart from being useful criteria for podzolic B horizons, both oxalate and pyrophosphate Fe and Al effectively separated the master podzolic B horizons of the four new great groups. Thus, it may be possible that the sesquioxide content could be used, in addition to total C, as differentiae for diagnostic podzolic B horizons.

For the purpose of a detailed examination of relationships between organic matter and sesquioxides it was pertinent, therefore, to present the data on the basis of the horizon diagnostic for the new great groups. Table 20 summarizes the means and standard deviations of these properties for the four diagnostic B horizons irrelevant of their great group membership. Although any Bh* horizon was a part of a Humic* Podzol, no certain great group membership could be assigned to Bf*, Bfh*, or Bhf* horizons.

TABLE 20. Means and standard deviations of total carbon and sesquioxides of the podzolic B horizons diagnostic for the new great groups

Diagnostic podzolic B horizon	Number of horizons	Total C	Oxalate-extractable			Pyrophosphate-extractable		
			Fe	Al	Fe & Al	Fe	Al	Fe & Al
			(%)					
Bh*	27	11.88 (2.15)[1]	2.50 (1.66)	4.50 (2.18)	7.00 (2.24)	1.45 (0.94)	3.03 (1.25)	4.48 (1.21)
Bhf*	67	7.61 (1.83)	1.84 (1.53)	3.19 (1.60)	5.04 (1.87)	1.31 (1.08)	2.00 (1.10)	3.31 (1.58)
Bfh*	83	4.25 (0.79)	1.29 (0.63)	2.57 (1.32)	3.86 (1.55)	0.62 (0.47)	1.21 (0.43)	1.83 (0.70)
Bf*	169	1.83 (0.64)	0.82 (0.44)	1.42 (0.76)	2.25 (0.82)	0.27 (0.19)	0.61 (0.28)	0.88 (0.39)

[1] Numbers in parenthesis are standard deviations.

Discriminant and correlation analyses were undertaken to determine whether a definite relationship exists between the accumulation of organic matter and sesquioxides in the diagnostic horizons. A discriminant analysis tests the ability of a set of variables to recognize predetermined groupings that have been independently defined. Using the set of 346 horizons and six sesquioxide variables, the analysis correctly classified 73.1% of the horizons into the four diagnostic horizons defined on the basis of total carbon (Table 21). Only two variables, totals of both oxalate and pyrophosphate Fe and Al, were utilized in the analysis, the latter contributing more significantly to the discrimination than the former. While the majority of Bf* horizons was correctly classified, the discrimination between the remaining horizons was not so successful, particularly for the Bhf* horizons.

TABLE 21. Jackknifed classification matrix

Original classification	Percent correct	Discriminant analysis			
		Bh*	Bhf*	Bfh*	Bf*
		Number of horizons classified into a diagnostic horizon			
Bh*	66.7	18	7	1	0
Bhf*	41.8	17	28	14	8
Bfh*	63.9	0	11	53	19
Bf*	91.1	0	1	14	154
Total	73.1				

Misclassified horizons were identified as members of a diagnostic horizon with either a higher or lower content of total carbon than the original horizon, or both. The 'downward reclassificaton' could be explained as the accumulation of organic matter resulting from pedoturbation by windthrow and slope processes where varying amounts of organic debris are buried and undergo decomposition, resulting in an increase in organic matter content without a corresponding increase in sesquioxide content. The in situ enrichment of organic matter resulting from root decomposition in old growth forests could also be responsible. No definitive explanation, however, is offered for the upward reclassification, i.e., greater accumulation of sesquioxides in relation to the level of total carbon. It is suggested that some Fe and Al in podzolic B horizons may be either of in situ origin or a result of decomposition of organic compounds associated with Fe and Al.

In summary, discriminant analysis was partly successful in reproducing the classification of diagnostic horizons based on the content of pyrophosphate and oxalate Fe and Al. Thus, the assumption that the sesquioxide content will be unique for each podzolic B horizon diagnostic for a great group was rejected. The analysis, however, suggested a strong positive correlation between organic matter and sesquioxide characteristics of podzolic B horizons.

Results of correlation analysis using total C and the six sesquioxide

variables of the former analysis are presented in Table 22. All correlation coefficients were highly significant ($P < 0.01$), suggesting a relatively strong dependence of sesquioxide concentrations on both organic matter content and other sesquioxide variables. The high correlation coefficient of 0.78 between oxalate and pyrophosphate Fe and Al was indicative of the overlapping nature of the extractions. The significant correlations were not surprising. Among high correlation coefficients with total C were those for oxalate and pyrophosphate Al, probably responsible for the high correlation coefficients for the sums of oxalate and pyrophosphate Fe and Al; these variables alone accounted for 53 and 69% of variation in total C, respectively. There was also a high correlation between oxalate and pyrophosphate Fe and oxalate and pyrophosphate Al.

Strong positive correlations between pyrophosphate Fe and Al and total C in podzolic B horizons and a number of organic constituents of the LFH layer of mesothermal Podzols were reported by Lowe and Klinka (1981). Where podzolization was strongly expressed as measured by the above two properties, a significant pool of acid-soluble, fulvic polyphenols was available in the LFH layer, either as a result of direct release from foliage or other plant residues, or as by-products of the decomposition of plant debris. The strongest podzolization was associated with the highest biological (mainly mycogeneous) activity, indicating that the illuviated organic materials are largely produced during decomposition rather than leached from undecomposed plant remains. Increased podzolization was found to be associated with the greatest accumulations of 'immature', less strongly coloured humic acids, again suggesting that podzol formation is dependent to a considerable degree on decomposition. Lowe and Klinka (1981) concluded that the accumulation of organic matter and sesquioxides in mesothermal Podzols must be influenced by conditions and processes in the forest floor, particularly with respect to the release and persistence of mobile organic constituents.

In the Podzols examined in this study total carbon was able to account for only 69% of the sum of pyrophosphate Fe and Al (Table 22). This would imply that other mechanisms, such as that proposed by Farmer (1982) or

TABLE 22. Correlation matrix for total carbon and extractable sesquioxides of the podzolic B horizons diagnostic for tentative great groups

Variable	Correlation coefficient (r)[1]						
Total C	1.00						
Oxalate Fe	0.52	1.00					
Oxalate Al	0.63	0.25	1.00				
Pyrophosphate Fe	0.59	0.82	0.22	1.00			
Pyrophosphate Al	0.80	0.37	0.74	0.44	1.00		
Oxalate Fe & Al	0.73	0.66	0.89	0.56	0.75	1.00	
Pyrophosphate Fe & Al	0.83	0.66	0.60	0.80	0.89	0.78	1.00

[1] All correlation coefficients are significant at $P < 0.01$.

perhaps the in situ weathering of Fe and Al discussed by Lewis (1976), have a role in the translocation and precipitation of organic matter, Fe, and Al in podzolic soils. However, the use of total carbon as a differentiating characteristic for the separation of podzolic soils of the great group level appears to be quite satisfactory.

In considering the use of organic matter and sesquioxide contents as indices of the strength of podzolic B horizon development, the Bh* horizon, diagnostic for Humic* Podzols, featured the most profound accumulation of these materials, with total C predominating over oxalate Fe and Al; the Bf* horizon, diagnostic for Ferric* Podzols, had the lowest concentrations of organic matter and sesquioxides with oxalate Fe and Al predominating over total C. Reviewing the discussion on climatic variation of mesic Podzols against this background, it may be concluded that podzol formation intensifies along the climosequence. At the onset of climatically controlled podzol development, sesquioxides accumulate in the Bf* horizon whereas the translocation of organic matter from the upper solum is less intensive. With increasing humidity, the intensity of both groups of processes increases; however, the processes leading to positive enrichment of the B horizon by both organic matter and sesquioxides appear to gain dominance. Thus, the Bf* and Bfh* horizons can be characterized by the predominant build-up of sesquioxides, whereas the accumulation of organic matter and sesquioxides is significant for the Bhf* and Bh* horizons.

Horizonation and Depth Functions of Total Carbon and Sesquioxides

The examination of horizon sequences in relation to the occurrence of non-podzolic, subsurface mineral horizons and diagnostic podzolic B horizons reveals horizonation trends for each new great group (Table 23.) The least expressed horizon pattern of Humic* Podzols featured predominantly Bh* and infrequently Bfh* horizons; umbric or albic horizons were rare and when present were thin and discontinuous. Ferro-Humic* Podzols were also found predominantly without A horizons but with strongly expressed Bhf* horizons. The pattern of Ae-less Podzols was indicative of intensive anti-horizonation processes, notably windthrown trees and slope processes which exert a strong influence on imperfectly to poorly drained sites in the wetter subzones of the CWH Zone, particularly in the CWHb/d ecotone (Klinka et al. 1980).

The horizonation trends for the remaining great groups are more pronounced than in Humic* or Ferro-Humic* Podzols. The occurrence of umbric horizons in Ah/B-Podzols reached a maximum in Ferric*, whereas albic horizons (Ae/B-Podzols) were most abundant, as well as thickest, in Humo-Ferric* Podzols. However, the occurence of Ae-less Podzols was common in both of these great groups.

Umbric horizons were characteristic of moderately well to poorly drained (mesic to hygric) sites where the soils were base-rich or enriched by seepage or the flow of fine materials on steep slopes in the climatic setting of the CWHa Subzone. They were associated with herbal Pseudotsuga menziesii or Thuja plicata plant communities and Moder or Mull humus forms. In contrast, the strongest and most common albic horizons were developed on very rapidly to well drained sites of both the CWHa and CWHb subzones where the soils were formed from coarse-skeletal, base-poor parent materials which tend to have low contents of mafic minerals and even silicates. The two associated forest communities were the ericaceous shrub (Gaultheria shallon or Vaccinium spp.) Pseudotsuga menziesii or Tsuga heterophylla, and mossy (Hylocomium splendens, Rhytidiadelphus loreus and Plagiothecium undulatum) Tsuga heterophylla with Mor humus forms.

Overall, horizonation trends involving the redistribution of various

TABLE 23. Weighted means and standard deviations[1] for total C, oxalate and pyrophosphate Fe and Al of mesothermal Podzols classified in the new great groups

Horizon	Number of horizons	Total C (%)	Oxalate-extractable Fe	Oxalate-extractable Al	Pyrophosphate-extractable Fe	Pyrophosphate-extractable Al
			(%)			
Humic* Podzols:						
Ah	2	15.0	1.68	5.16	0.87	2.60
		(5.16)	(0.02)	(2.34)	(0.14)	(0.93)
Ae	3	2.40	0.78	0.56	0.23	0.28
		(1.26)	(0.33)	(0.40)	(0.36)	(0.19)
Bh*	24	12.5	2.24	4.85	1.36	3.28
		(2.02)	(1.79)	(2.31)	(0.91)	(1.21)
Bhf*	3	8.19	1.53	5.34	0.95	3.60
		(1.28)	(0.01)	(2.11)	(1.00)	(3.53)
Bfh*	10	4.23	1.81	3.44	0.63	1.31
		(0.72)	(0.65)	(1.14)	(0.28)	(0.27)
Ferro-Humic* Podzols:						
Ah	10	7.33	0.81	1.47	0.61	1.13
		(4.40)	(0.30)	(0.94)	(0.30)	(0.70)
Ae	12	3.75	0.55	0.27	0.32	0.21
		(3.62)	(0.53)	(0.13)	(0.43)	(0.12)
Bhf*	60	7.57	1.74	3.36	1.25	2.09
		(1.10)	(1.19)	(1.50)	(1.09)	(0.78)
Bfh*	17	4.17	1.65	3.04	0.97	1.30
		(0.72)	(0.51)	(1.35)	(0.46)	(0.38)
Bf*	10	2.16	0.84	1.71	0.31	0.61
		(0.56)	(0.29)	(1.16)	(0.27)	(0.27)
Humo-Ferric* Podzols:						
Ah	17	9.24	0.63	0.83	0.43	0.73
		(4.07)	(0.46)	(0.64)	(0.23)	(0.40)
Ae	34	2.70	0.16	0.15	0.06	0.13
		(1.20)	(0.22)	(0.24)	(0.10)	(0.17)
Bfh*	54	4.14	1.04	2.44	0.48	1.23
		(0.82)	(0.51)	(1.30)	(0.47)	(0.45)
Bf*	44	1.96	0.65	1.86	0.20	0.67
		(0.59)	(0.33)	(0.70)	(0.23)	(0.27)
Ferric* Podzols:						
Ah	21	5.72	1.11	0.84	0.55	0.62
		(2.47)	(0.59)	(0.56)	(0.34)	(0.35)
Ae	14	2.69	0.29	0.23	0.20	0.31
		(1.15)	(0.14)	(0.16)	(0.12)	(0.24)
Bf*	115	1.68	0.82	1.25	0.27	0.59
		(0.66)	(0.48)	(0.67)	(0.16)	(0.30)
Bm	3	0.39	0.80	0.71	0.91	0.23
		(0.10)	(0.04)	(0.15)	(0.03)	(0.03)

[1] Numbers in parenthesis are standard deviations.

consituents, notably organic matter and sesquioxides within the solum, appear to be weakly expressed. This was considered by Lewis (1976) to be one of the major characteristics of mesothermal Podzols. Using mesic Podzols as benchmarks, the thickness and morphological changes in surface organic horizons were attributed largely to the effects of regional climate (Lewis 1976, Lowe and Klinka 1981). The thickness of albic horizons was attributed to the effects of soil parent material lithology (Lewis 1976), regional climate (Brooke et al. 1970, Klinka 1976), and humus form (Klinka and Lowe 1981). The thickness of umbric horizons was attributed to the effects of regional climate, soil moisture and nutrient regime, and vegetation (Krajina 1963, 1969; Klinka 1976).

Depth functions of total C and extractable Fe and Al for the new great groups are presented in Table 23. The largest concentrations of sesquioxides appear to be characteristic for the uppermost podzolic B horizons, decreasing along the genetic gradient from Humic* to Ferric* Podzols and the depth gradient. This is not surprising in view of discussed relationships between total C and sesquioxides and the sequence of podzolic B horizons in the soils.

Umbric horizons were consistently higher in total carbon and lower in sesquioxides than podzolic B horizons, indicating that in mesothermal Ah/B Podzols, which, as a rule, do not have albic horizons, the accumulation of organic matter in A horizons is more intensive than its illuviation into B horizons. Occasionally, however, the pyrophosphate Fe and Al content of umbric horizons of Humo-Ferric* and Ferric* Podzols was greater than that of the underlying Bfh* or Bf* horizons. This was noted by Klinka et al. (1981b) and Inselberg (1982) as the characteristic feature of Umbric* Humo-Ferric* Podzols formed on deep, base-rich alluvial terraces (Figure 10). Such a pattern suggests that the accumulation of both organic matter and pyrophosphate-extractable sesquioxides takes place in the A horizon. These soils, featuring well expressed umbric horizons and Vermimull humus forms, showed a gradual decrease of total carbon and pyrophosphate Fe and Al with depth, whereas oxalate Fe and Al showed a distinct peak in the underlying B horizon.

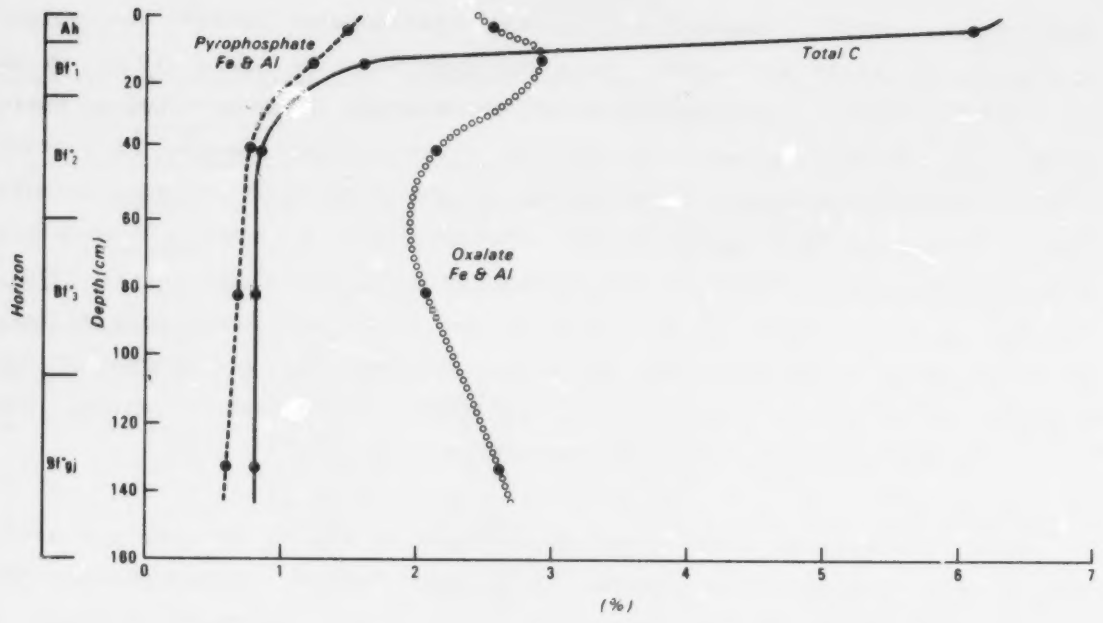

FIGURE 10. Depth functions of total C and extractable sesquioxides within the pedon of fine-loamy Umbric* Ferric* Podzol with Vermimull on alluvial terrace (sample plot No. 024, Cameron River Valley).

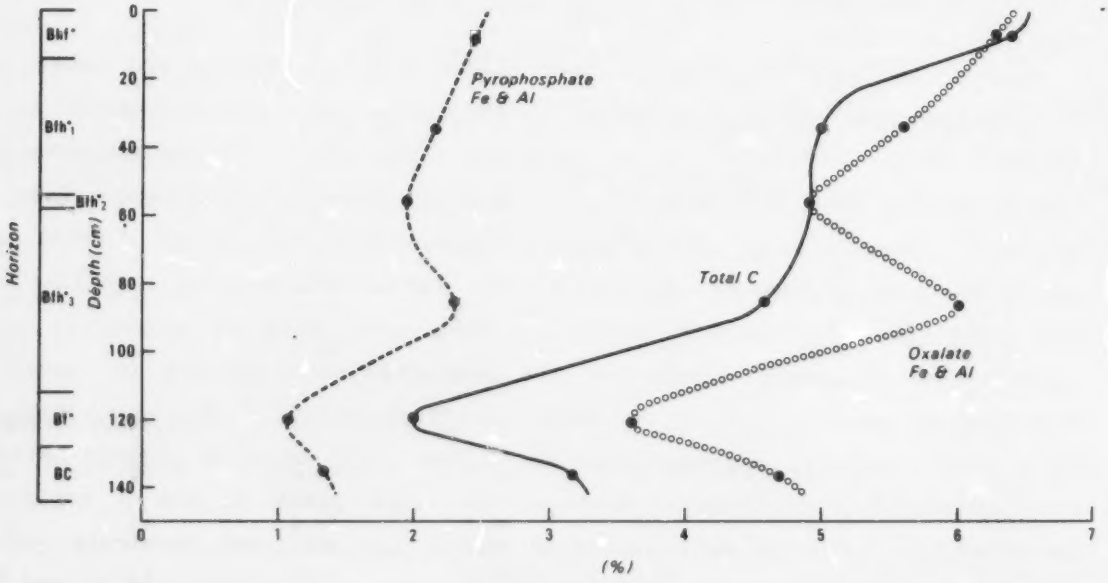

FIGURE 11. Depth functions of total C and extractable sesquioxides within the pedon of coarse-skeletal Spodic* Ferro-Humic* Podzol with Mormoder on basaltic till (sample plot No. 038, Koprino River Watershed).

The A-less Podzols, in general, showed a gradual decrease of total C and sesquioxides with depth, but, when examined on an individual basis, there was usually a secondary stratum of sesquioxide accumulation underneath the uppermost podzolic B horizon (Figure 11). This pattern varied depending on the horizon sequence within the master B horizon. In the imperfect to poorly drained Podzols it was not uncommon for the B horizon with the highest content of total C and sesquioxides to be located in the lower solum just above the compacted till layer.

Albic horizons relative to podzolic B horizons showed markedly low contents of both total C and sesquioxides with the exception of some Ferric* Podzols in which the content of total C was higher than that of the underlying Bf* horizons. Thus, the Ae/B-Podzols, which typically do not have umbric horizons, featured more intensive movement of organic matter and sesquioxides than the A-less Podzols, though their redistribution within the soils was restricted to a relatively narrow depth range (Figure 12).

In summary, the horizonation and depth functions for mesothermal Podzols conformed to those described by Lewis (1976) for the Vancouver Island Podzols. The typical mesothermal Podzol is an A-less Podzol with Mor humus form where the spodic horizon is sesquioxide-rich, particularly near or at the mineral soil surface. A combination of mesothermal climate and iron-rich and quartz-poor materials produces a large amount of weathered sesquioxides and results in losses of amorphous silica and bases to drainage waters. The formation of albic horizons is retarded or even prevented because of a rapid insolubilization of organic complexes by metal loading. Therefore, the extent of translocation of sesquioxides is small, whereas their accumulation in the B horizon through residual enrichment is large.

The formation of Ah/B or Ae/B Podzols is dependent largely on regional climate, parent materials, and soil moisture regime characteristics. Their horizonation, however, remains weakly expressed and the processes involved in their formation are essentially similar to those described for the A-less Podzols.

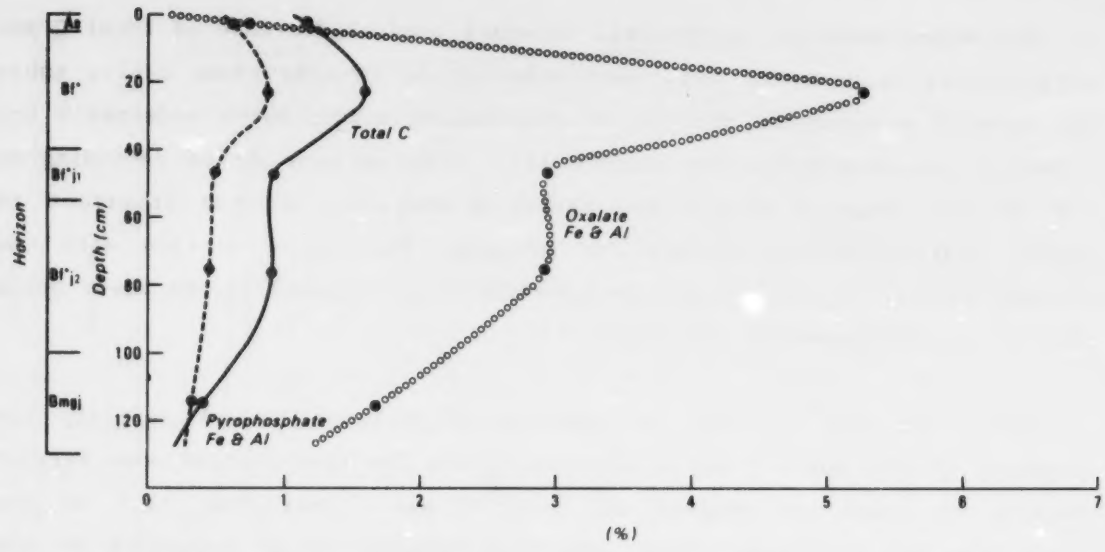

FIGURE 12. Depth functions of total C and extractable sesquioxides within the pedon of sandy Albic* Ferric* Podzol, gleyed phase, with Humimor on glaciofluvial materials (sample plot No. 001, University of B.C. Research Forest).

Relationships Between the New Great Groups and Climate

As a result of differences in relief, soil parent materials, vegetation, climatic, and past disturbances, well defined relationships between the new great groups and regional climates cannot be expected. These relationships can be interpreted in two ways (Table 24). A relationship may be based on the number of pedons classified into a particular great group or the relationship may be based on the number of pedons occurring in a biogeoclimatic unit. For example, in the first case, 48% of Ferric* Podzols occurred in the CWHal Variant, whereas, in the second case, 84% of the pedons located in the CWHal Variant were Ferric* Podzols.

On the basis of 177 pedons which were classified into the new great groups, 12.4% were Humic*, 22.6% Ferro-Humic*, 36.7% Humo-Ferric*, and 28.3% were Ferric* Podzols.

Humic* Podzols were associated predominantly with poorly drained sites in the CWHb subzone and CWHb/d ecotone; their occurrence in the CWHa2 Variant was limited to unstable, excessively steep, colluvial slopes.

TABLE 24. Relationship between the new great groups and biogeoclimatic units

New great group	Climate/biogeoclimatic unit			
	wetter Csb-drier Cfb CWHa1	drier Cfb CWHa2	wetter Cfb-Cfc CWHb2	cooler and wettest Cfb CWHb/d
Humic* Podzols	0/0[1]	5/2	62/20	33/22
Ferro-Humic* Podzols	0/0	23/18	37/24	40/55
Humo-Ferric* Podzols	6/16	38/49	47/50	9/20
Ferric* Podzols	48/84	40/31	10/6	2/3

[1] Numerators in horizontal rows are percent of pedons which are members of the same new great group associated with a biogeoclimatic unit; denominators in vertical rows are percent of pedons which are members of the same biogeoclimatic unit associated with a new great group.

Ferro-Humic* Podzols showed a similar distribution; however, their occurrence on imperfectly to poorly drained (seepage) sites in the CWHa2 Variant was more frequent than those of Humic* Podzols. Humo-Ferric* Podzols occurred in all units but were clearly less common in the CWHa1 variant and CWHb/d ecotone. Finally, Ferric* Podzols were most common on a wide variety of sites in the CWHa1 and CWHa2 Variants, while their occurrence in the CWHb2 variant and CWHb/d ecotone was marginal.

A complimentary relationship emerged when each classified pedon was assigned a membership in a biogeoclimatic taxon. The driest and warmest CWHa1 Variant featured the majority of Ferric* Podzols, while the wettest and coolest CWHb/d ecotone was clearly associated with Ferro-Humic* and Humic* Podzols. Ferric* and Humo-Ferric* Podzols were predominant in the CWHa2 Variant, whereas the CWHb2 Variant featured Humic*, Humo-Ferric*, and Ferro-Humic* Podzols as the major soils.

It may be concluded that the members of each new great group has a

characteristic distribution pattern in relation to biogeoclimatic units, and each biogeoclimatic unit has a characteristic distribution pattern of Podzols in relation to the new great group classification. The relationship discussed earlier between climate and some characteristics of mesic Podzols, which was used to derive criteria for the new great groups, appears to render reasonable relationships and a logical arrangement for the whole population of the studied Podzols.

Characterization of the New Great Groups

Humic* Podzols

Horizon sequence[1]: LFH (or LF and H); Bh*(g), (Bhf*g), Bfh*(g)

Humic* Podzols were separated by cluster analysis in a single group cluster (D) with the following subdivision and horizon sequences:

D1 - LF, H; Bh*(g)
D2 - LFH; Bh*, Bfh*(g)
D3 - LFH; Bh*(g)

Two subgroups, folisolic* and spodic*, both more or less gleyed, were recognized (Table 17). No taxonomic importance was given to clusters D2 and D3 because they were separated on the basis of the composition of the master podzolic B horizons, which had been strongly influenced by pedoturbation.

These soils had thick surface organic horizons which under climax or near climax conditions were commonly in excess of 40 cm forming intergrades to the Organic Order. A great quantity of decaying wood was a constant part of finely decomposed organic materials which represent the major rooting zone of the vegetation. Subsurface H or Oh horizons were somewhat compacted, dark reddish gray or very dark gray in colour, and had a distinct greasy character. These horizons inhibit downward percolation of water and some exhibited seepage flow. The Ahe or Ae horizons were thin and discontinuous, often masked by infiltrated humus materials. Surface organic horizons were underlain by a very dark reddish brown Bh* horizon that averaged 24.5 cm in thickness, and contained in excess of 10% total C and large quantities of extractable sesquioxides (Table 25). The mean value of pyrophosphate Fe for this great group was 1.36% and, therefore, none of these pedons from the perhumid climatic environment could be classified as a proper Humus* Podzol.

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1 Parenthesis indicate less significant or less common horizons or features.

TABLE 25. Weighted means and standard deviations[1] of some chemical properties for layers and horizons and master layers and horizons of 22 Humic* Podzols

Layer or horizon	Number of layers or horizons	Thickness (cm)	pH (CaCl)	Total C (%)	Total N (%)	C/N	Exchangeable cations				CEC	BS	Oxalate-extractable		Pyrophosphate-extractable	
							Ca	Mg	Na	K	(meq/100g)	(%)	Fe	Al	Fe	Al
							(meq/100g)						(%)			
Layers and horizons:																
Lf	22	11.3 (8.99)	3.5 (0.50)	47.8 (7.73)	1.31 (0.47)	40.9 (21.2)	9.37 (11.2)	5.07 (4.16)	0.75 (0.43)	1.50 (0.89)	108.4 (28.6)	17.1 (11.3)	- -	- -	- -	- -
H or Oh	9	13.4 (7.78)	3.9 (0.76)	42.6 (10.80)	0.98 (0.34)	46.5 (19.1)	8.23 (17.9)	4.50 (6.04)	0.71 (0.61)	0.52 (0.31)	127.5 (24.6)	10.3 (14.8)	0.11 (0.44)	0.35 (1.42)	0.42 (0.39)	2.67 (2.08)
Ah	2	12.5 (10.6)	5.2 (1.06)	15.0 (5.16)	1.16 (0.37)	13.0 (0.49)	15.9 (13.4)	1.67 (1.25)	0.16 (0.04)	0.24 (0.04)	89.3 (43.8)	18.1 (13.0)	1.68 (0.02)	5.16 (2.34)	0.87 (0.14)	2.60 (0.93)
Ae	3	3.7 (2.1)	4.2 (0.87)	2.40 (1.26)	0.06 (0.05)	32.0 (10.3)	0.83 (0.32)	0.19 (0.18)	0.13 (0.05)	0.09 (0.04)	11.7 (7.21)	11.0 (1.56)	0.78 (0.33)	0.56 (0.40)	0.23 (0.36)	0.28 (0.19)
Bh*	24	24.5 (13.8)	4.4 (0.39)	12.5 (2.02)	0.57 (0.26)	26.2 (10.7)	2.39 (5.83)	0.38 (0.61)	0.23 (0.20)	0.28 (0.24)	74.6 (29.8)	3.4 (3.8)	2.24 (1.79)	4.85 (2.31)	1.36 (0.91)	3.28 (1.21)
Bhf*	3	20.0 (5.0)	4.7 (0.26)	8.19 (1.28)	0.40 (0.03)	20.7 (4.44)	0.10 (0.13)	0.07 (0.04)	0.15 (0.20)	0.14 (0.12)	65.1 (25.2)	0.6 (0.4)	1.53 (0.81)	5.34 (2.11)	0.95 (1.0)	3.60 (3.53)
Bfh*	10	30.7 (10.8)	4.8 (0.28)	4.23 (0.72)	0.22 (0.10)	23.6 (14.4)	1.10 (0.77)	0.14 (0.09)	0.25 (0.19)	0.14 (0.08)	33.7 (4.21)	4.9 (3.0)	1.81 (0.65)	3.44 (1.14)	0.63 (0.28)	1.31 (0.27)
Master layers and horizons:																
LFH	31	16.8 (8.84)	3.6 (0.66)	44.8 (8.51)	1.24 (0.40)	42.9 (20.1)	9.01 (13.4)	4.95 (5.00)	0.73 (0.52)	1.13 (0.57)	118.8 (26.9)	15.2 (12.7)	- -	- -	- -	- -
A	5	7.2 (7.3)	4.9 (0.94)	11.2 (6.26)	0.83 (0.53)	18.8 (11.3)	11.3 (8.46)	1.21 (0.81)	0.15 (0.05)	0.20 (0.73)	65.6 (38.8)	15.9 (6.7)	1.41 (0.55)	3.75 (2.38)	0.67 (0.43)	1.89 (1.18)
B	3	25.8 (12.7)	4.5 (0.41)	9.56 (3.95)	0.45 (0.26)	25.0 (11.3)	1.83 (4.71)	0.29 (0.50)	0.23 (0.19)	0.22 (0.21)	60.8 (30.2)	3.7 (3.6)	2.06 (1.52)	4.43 (2.99)	1.10 (0.86)	2.67 (1.60)

[1] Numbers in parenthesis are standard deviations.

Humic* Podzols were largely confined to the wetter subzones of the CWH Zone. They occurred typically on imperfectly to poorly drained sites of lower slopes and depressions. Abundant precipitation and additional input of moisture from upslope, combined with low temperature (CWHb/d) or shorter growing season (CWHb2), limit mineralization of organic materials. As a result, Pachic Humimor or Hydromor humus forms have developed. Humic* Podzols were predominantly associated with the hygrophytic Tsuga- or Abies-Blechnum communities featuring productive growth of both amabilis fir and western hemlock. Some of the Humic* Podzols in the CWHb2 Variant occurred on very steep colluvial slopes or on the slopes of ravines supporting very productive Thuja- or Pseudotsuga-Polystichum communities.

Ferro-Humic* Podzols

Horizon sequence: LFH, (LF, H); (Ahe, Ae); Bhf*, (Bfh*, Bf*)

Ferro-Humic* Podzols were separated by cluster analysis into three groups (cluster A, B, and C) and two of those were further subdivided into several groups each with a unique horizon sequence:

A - LF, H; (Ae); Bhf*(g)
B1 - LFH; (Ahe); Bhf*
B2 - LFH; Bhf*
B3 - LFH; Bhf*, Bf*
C1 - LFH, (LF, H); Bhf*(g), Bfh*(g)
C2 - LFH; Ae; Bhf*(c), (Bfh*, Bf*)

Similar sequences of the non-podzolic horizons were suggestive of subgroups but it was uncertain what taxonomic significance should be given to the different sequences of podzolic B horizons. Undoubtedly, horizon sequences indicating distribution of various constituents, notably organic matter, nitrogen and sesquioxides within the podzolic B horizons may be of considerable pedogenic and ecological significance. However, as noted by Lewis (1976), they can be disrupted by the effects of colluvial processes and pedoturbation (mainly windthrown trees), modified by the action of ground water and forest vegetation, or the horizonation of podzolic B horizons may simply be a function of soil depth, i.e., shallow soils could be expected to have a more uniform sequence than deeper soils. It is suggested that such differences should be dealt with at below-subgroup categories, possibly at the series level.

Ferro-Humic* Podzols had thick surface organic horizons which may, as in Humic* Podzols, feature thick subsurface H horizons. The underlying Ahe or Ae horizons were more common than in Humic* Podzols but less common and less well expressed than in Humo-Ferric* Podzols. The diagnostic Bhf* horizons were dark reddish brown and had a mean thickness of 26.5 cm. The master podzolic B horizon included several Bhf* horizons or, at a greater depth, it graded into gleyed Bfh* or, less frequently, Bf* horizons. Some chemical properties for the Ferro-Humic* Podzol Great Group are summarized in Table 26. Ferro-Humic* Podzols occurred in the wetter mesothermal climate; in the drier mesothermal climate they were found exclusively on imperfectly to poorly drained sites.

TABLE 26. Weighted means and standard deviations[1] of some chemical properties for layers and horizons and master layers and horizons of 40 Ferro-Humic* Podzols

Layer or horizon	Number of layers or horizons	Thickness (cm)	pH (CaCl)	Total C (%)	Total N (%)	C/N	Exchangeable cations				CEC	BS	Oxalate-extractable		Pyrophosphate-extractable	
							Ca	Mg	Na	K	(meq/100g)	(%)	Fe	Al	Fe	Al
Layers and horizons:																
LF	40	12.8 (9.0)	3.3 (0.70)	43.4 (10.32)	1.25 (0.35)	37.8 (14.4)	10.3 (7.06)	4.90 (3.95)	0.70 (0.46)	1.44 (0.95)	102.8 (27.8)	15.9 (12.9)	- -	- -	- -	- -
H or Oh	14	14.4 (8.38)	3.7 (0.61)	43.2 (13.37)	1.30 (0.50)	36.5 (15.8)	14.1 (15.6)	7.46 (6.00)	0.64 (0.28)	0.62 (0.21)	120.2 (37.2)	17.6 (11.4)	0.08 (0.71)	0.09 (0.78)	0.14 (0.63)	0.18 (0.47)
Ah	10	10.5 (8.77)	4.3 (0.51)	7.33 (4.40)	0.54 (0.35)	15.1 (7.3)	3.41 (3.98)	0.57 (0.58)	0.11 (0.09)	0.19 (0.15)	39.1 (20.9)	10.4 (8.5)	0.81 (0.30)	1.47 (0.94)	0.61 (0.30)	1.13 (0.70)
Ae	12	5.3 (3.8)	3.4 (0.33)	3.75 (3.62)	0.15 (0.23)	27.8 (9.8)	0.90 (2.12)	0.39 (0.94)	0.13 (0.14)	0.20 (0.72)	24.6 (18.0)	5.6 (5.2)	0.55 (0.53)	0.27 (0.13)	0.32 (0.43)	0.21 (0.12)
Bhf*	60	26.5 (17.3)	4.4 (0.35)	7.57 (1.10)	0.37 (0.12)	22.1 (6.8)	1.42 (1.79)	0.30 (0.68)	0.13 (0.08)	0.20 (0.24)	47.0 (7.7)	4.6 (5.7)	1.74 (1.19)	3.36 (1.50)	1.25 (1.09)	2.09 (0.78)
Bfh*	17	28.8 (17.4)	4.5 (0.40)	4.17 (0.72)	0.19 (0.72)	22.7 (5.7)	0.58 (0.44)	0.20 (0.20)	0.12 (0.04)	0.05 (0.03)	31.1 (5.6)	3.1 (2.1)	1.65 (0.51)	3.04 (1.35)	0.97 (0.46)	1.30 (0.38)
Bf*	10	32.7 (10.0)	4.6 (0.30)	2.16 (0.56)	0.13 (0.04)	17.7 (3.6)	1.10 (1.39)	0.18 (0.26)	0.08 (0.02)	0.08 (0.04)	25.3 (6.1)	6.4 (6.9)	0.84 (0.29)	1.71 (1.16)	0.31 (0.27)	0.61 (0.27)
Master layers and horizons:																
LFH	54	17.8 (9.24)	3.4 (0.63)	43.3 (12.14)	1.28 (0.37)	37.6 (14.6)	11.7 (9.49)	5.91 (5.17)	0.69 (0.43)	1.23 (0.73)	112.0 (31.6)	16.51 (12.5)	- -	- -	- -	- -
A	22	7.7 (6.9)	4.0 (0.54)	5.97 (4.40)	0.39 (0.34)	19.9 (10.0)	2.46 (3.27)	0.50 (0.78)	0.12 (0.12)	0.20 (0.53)	33.6 (21.1)	8.6 (6.9)	0.71 (0.43)	1.01 (0.77)	0.50 (0.38)	0.78 (0.63)
B	87	27.4 (16.7)	4.5 (0.37)	6.15 (2.25)	0.30 (0.14)	21.6 (6.5)	1.31 (1.80)	0.26 (0.58)	0.12 (0.07)	0.15 (0.21)	40.8 (11.0)	4.5 (5.3)	1.60 (1.06)	3.07 (1.48)	1.07 (0.99)	1.73 (0.81)

[1] Numbers in parenthesis are standard deviations.

Clusters A and C1 are alike, both having H horizons; clusters B1 and C2 are also alike, having Ahe and Ae horizons, respectively. Clusters B2 and B3 have none of those subsurface horizons. The difference between these pairs of clusters lies in their sequence of podzolic B Horizons.

Most of the pedons in the CWHb/d ecotone classified as Humo-Ferric* Podzols were included in clusters A and C1. These pedons were found on sites influenced by subsurface seepage flow, though the soils in cluster C1 were slightly drier (less gleyed) and often lacked thick H horizons. The mid-elevation Abies-Streptopus and low-elevation Tsuga- or Abies-Blechnum were the associated forest communities, and Pachic Mors or Hydromors were the associated humus forms for both clusters.

Ferro-Humic* Podzols with poorly expressed umbric horizons were included in cluster B1 while those with well formed albic horizons and incipient

cementation in podzolic B horizons were included in cluster C2. The slightly drier Ferro-Humic* Podzols of cluster B1 featured Mormoder or Mullmoder humus forms and were associated predominantly with the colluvial Thuja-Polystichum communities. The mid-elevation Ferro-Humic* Podzols of cluster C2 featured Mors and supported either colluvial Thuja-Polystichum or depressional Abies-Streptopus communities.

The soils grouped in clusters B2 and B3 occurred mainly on seepage sites in the CWHa2 Variant. They were associated predominantly with productive Thuja- or Pseudotsuga-Polystichum communities and less acid Mormoder or Mullmoder humus forms.

Humo-Ferric* Podzols

Horizon sequence: LFH; (Ah or Ae); Bfh*, Bf*

Humo-Ferric* Podzols were delineated by cluster analysis into two groups (cluster E and G) with each of these further subdivided into several groups, each featuring a unique horizon sequence:

E1 - LFH; Ae
E2 - LFH; Ae; Bfh*
E3 - LFH; Bfh*
E4 - LFH; Ah; Bfh*, (Bf*g)
G1 - LFH; Ae; Bfh*, Bf*
G2 - LFH; Bfh*, Bf*
G3 - LFH; (Ah); Bfh*(g), Bf*(g)

This great group comprises pedons with well formed umbric (E4 and G3) and albic (E1, E2 and G1) horizons as well as those representing A-less Podzols (E3 and G2). Since the E and G clusters differ in the absence and presence of Bf* horizons, this separation is not considered to be taxonomically significant, at least at the subgroup level, as discussed in the preceding section.

Humo-Ferric* Podzols had moderately thick surface organic horizons with F and H horizons of about the same thickness. The diagnostic Bfh* horizons had a mean thickness of 27.4 cm and were brown to reddish brown. The master podzolic B horizon consisted of several Bfh* or Bfh* and Bf* horizons, the latter sequence being more typical for deeper soils. On seepage sites, this sequence was usually reversed, with Bfh* horizons found in the lower solum. Some chemical properties for the Humo-Ferric* Podzol Great Group are summarized in Table 27.

Humo-Ferric* Podzols were predominantly found in the drier mesothermal climate; however, they also occurred in the wetter mesothermal climate although only on drier sites. Cluster E was comprised of pedons having a greater occurrence in the wetter than in the drier subzones; cluster G grouped the Bfh*/Bf* pedons found mainly in the CWHal Variant.

Cluster E1 separated a special group of soils from the CWHb2 Variant which featured an LFH-Ae horizon sequence with an occasional, incipient podzolic B horizon over bedrock. They were found on excessively to rapidly drained sites, usually rock outcrops. Interestingly, in spite of the lack of diagnostic podzolic B horizons, they were grouped according to the total carbon content of the LFH layer and the presence of Ae horizons together with Humo-Ferric* Podzols. These pedons, classified by Lavkulich and Klinka as Lithic Podzols (Klinka 1976), can be interpreted as a 'truncated' variation of Humo-Ferric* Podzols. Lithic Podzols are related to Lithic Folisols (Lewis and Lavkulich 1972) which also feature the LFH-Ae horizon sequence but with the thickness of organic horizons greater than that of the underlying albic horizon. Lithic Podzols are believed to have formed from shallow, in situ weathered materials under the influence of a perhumid climate. They are extremely acid and nutrient-poor (Table 28), able to support low productivity Tsuga-Gaultheria communities.

Cluster E2 was composed of pedons with well formed albic horizons found either on drier or wetter sites in the wetter subzones of the CWH Zone. Strongly acid, thick Mor humus forms and base-poor parent materials were the two common properties of these pedons. The mean thickness of 14.3 cm for

TABLE 27. Weighted means and standard deviations[1] of some chemical properties for layers and horizons and master layers and horizons of 65 Humo-Ferric* Podzols

Layer or horizon	Number of layers or horizons	Thickness (cm)	pH (CaCl	Total C (%)	Total N (%)	C/N	Exchangeable cations Ca	Mg	Na	K	CEC	BS	Oxalate-extractable Fe	Al	Pyrophosphate-extractable Fe	Al
							(meq/100g)				(meq/100g)	(%)	(%)			
Layers and horizons:																
LFH	65	10.0 (7.24)	3.5 (0.54)	45.3 (9.36)	1.36 (0.33)	34.6 (9.14)	12.6 (10.6)	3.04 (1.99)	0.77 (0.49)	2.23 (1.14)	122.7 (36.3)	16.7 (12.7)	- -	- -	- -	- -
Ah	17	8.6 (4.8)	4.3 (0.34)	9.24 (4.07)	0.59 (0.23)	[illegible] (4.33)	5.25 (4.13)	0.85 (0.70)	0.13 (0.24)	0.33 (0.40)	47.3 (19.1)	12.8 (8.42)	0.63 (0.46)	0.83 (0.64)	0.43 (0.23)	0.73 (0.40)
Ae	34	10.9 (9.20)	3.4 (0.47)	2.70 (1.20)	0.16 (0.11)	20.7 (10.4)	0.76 (1.09)	0.16 (0.12)	0.07 (0.04)	0.21 (0.17)	16.7 (7.92)	7.1 (4.7)	0.16 (0.22)	0.15 (0.24)	0.06 (0.10)	0.13 (0.17)
Bfh*	54	27.4 (16.2)	4.5 (0.35)	4.14 (0.82)	0.28 (0.14)	18.7 (12.9)	0.76 (0.90)	0.18 (0.60)	0.06 (0.06)	0.12 (0.09)	34.5 (10.8)	3.4 (3.9)	1.04 (0.57)	2.44 (1.30)	0.48 (0.47)	1.23 (0.45)
Bf*	44	34.5 (13.7)	4.8 (0.28)	1.96 (0.59)	0.13 (0.06)	18.4 (17.9)	0.43 (0.54)	0.21 (0.67)	0.12 (0.13)	0.09 (0.06)	22.7 (9.03)	4.1 (4.8)	0.65 (0.33)	1.86 (0.70)	0.20 (0.23)	0.67 (0.27)
Master layers and horizons:																
LF	65	10.0 (7.24)	3.5 (0.54)	45.3 (9.36)	1.36 (0.33)	34.6 (9.14)	12.6 (10.6)	3.04 (1.99)	0.77 (0.49)	2.23 (1.14)	122.7 (36.3)	16.7 (12.7)	- -	- -	- -	- -
A	51	10.2 (8.0)	3.7 (0.54)	4.55 (3.87)	0.28 (0.26)	19.4 (9.21)	2.03 (3.02)	0.36 (0.49)	0.09 (0.15)	0.25 (0.28)	25.4 (19.4)	8.7 (6.4)	0.29 (0.35)	0.34 (0.48)	0.17 (0.23)	0.30 (0.38)
B	98	30.9 (15.7)	4.6 (0.37)	3.22 (1.60)	0.22 (0.15)	18.4 (15.0)	0.61 (0.75)	0.20 (0.62)	0.10 (0.10)	0.11 (0.08)	28.8 (11.2)	3.8 (4.3)	0.85 (0.55)	2.09 (1.09)	0.36 (0.49)	0.95 (0.45)

[1] Numbers in parenthesis are standard deviations.

TABLE 28. Weighted means and standard deviations[1] of some chemical properties for layers and horizons of 10 Lithic (Humo-Ferric*) Podzols separated in cluster E1

Layer or horizon	Number of layers or horizons	Thickness (cm)	pH (CaCl	Total C (%)	Total N (%)	C/N	Exchangeable cations Ca	Mg	Na	K	CEC	BS	Oxalate-extractable Fe	Al	Pyrophosphate-extractable Fe	Al
							(meq/100g)				(meq/100g)	(%)	(%)			
Layers and horizons:																
LFH	10	9.0 (4.8)	3.4 (0.32)	45.8 (11.26)	1.24 (0.28)	40.0 (9.47)	10.3 (6.08)	2.89 (1.52)	0.64 (0.38)	2.80 (1.29)	104.7 (23.2)	15.7 (6.5)	- -	- -	- -	- -
Ae	11	15.3 (7.7)	3.2 (0.13)	2.94 (1.16)	0.14 (0.04)	21.6 (5.28)	0.31 (0.24)	0.16 (0.07)	0.08 (0.03)	0.24 (0.20)	12.9 (4.92)	6.5 (3.2)	0.08 (0.12)	0.05 (0.04)	0.02 (0.02)	0.04 (0.03)

[1] Numbers in parenthesis are standard deviations.

the LFH layer was the highest value found in the Humo-Ferric* Podzol Great Group. Cluster G1 also included pedons with albic horizons and Mor humus forms, but these were found mainly in the CWHa2 Variant on sites that were highly variable in soil moisture regime, floristic composition, and productivity of the associated forest communities.

Slightly gleyed pedons featuring umbric horizons were grouped in clusters E4 and G3. They were found most frequently on wetter sites

influenced by subsurface seepage flow and supported a series of very productive Thuja- or Pseudotsuga-Polystichum communities with humus forms ranging from Mormoders and Moders to Mulls.

Clusters E3 and G2 were composed of pedons found on sites in the CWHb2 and CWHa2 variants that were highly variable in soil moisture regime. As a result, the associated forest communities varied correspondingly in their floristic composition and productivity; however, Mor humus forms were characteristic of pedons in both clusters.

Ferric* Podzols

Horizon sequence: LFH; (Ah or Ae); Bf*, (Bm)

Ferric* Podzols were separated by cluster analyses into a single group (cluster F). This group was further subdivided into three groups based on the sequence of subsurface mineral horizons. The following differentiated clusters were suggestive of umbric*, albic*, and spodic* subgroups:

F1 - LFH; Ah, (Ae); Bf(g)
F2 - LFH; (Ae); Bf, (Bfj or Bm)
F3 - LFH; Bf

The Ferric* Podzols had thin surface organic horizons which were commonly underlain by well formed Ah or Ae horizons usually less than 10 cm thick. The diagnostic Bf* horizons were dark to light yellowish brown, and had a low content of organic C and extractable sesquioxides. In fact, some Bf* horizons appeared to be intergrades between podzolic and brunisolic B horizons when both morphological and chemical criteria were used for their classification. The podzolic B horizons included several Bf* horizons, occasionally with Bm and BC horizons under the Bf* horizons. Some chemical properties of the Ferric* Podzol Great Group are summarized in Table 29. Mean values for the Bf* horizon are as follows: total C 1.68%, pyrophosphate Fe and Al 0.86%, pyrophosphate Fe 0.27%, and the ratio of total carbon to pyrophosphate Fe 6.2.

TABLE 29. Weighted means and standards deviations[1] of some chemical properties for layers and horizons and master layers and horizons of 50 Ferric* Podzols

Layer or horizon	Number of layers or horizons	Thickness (cm)	pH ($CaCl_2$)	Total C (%)	Total N (%)	C/N	Exchangeable cations				CEC (meq/100g)	BS (%)	Oxalate-extractable		Pyrophosphate-extractable	
							Ca	Mg	Na	K			Fe	Al	Fe	Al
							(meq/100g)						(%)			
Layers and horizons:																
LFH	50	8.4 (5.2)	3.5 (0.92)	43.3 (8.82)	1.19 (0.37)	39.0 (11.9)	19.8 (12.0)	3.70 (1.74)	0.63 (0.47)	2.25 (1.33)	99.1 (43.4)	30.5 (21.4)	- -	- -	- -	- -
Ah	21	9.9 (7.6)	4.5 (0.48)	5.72 (2.47)	0.30 (0.16)	19.7 (6.55)	7.20 (6.82)	0.89 (0.58)	0.29 (1.72)	0.23 (0.13)	34.2 (17.5)	26.9 (20.7)	1.11 (0.59)	0.84 (0.56)	0.55 (0.34)	0.62 (0.35)
Ae	14	9.1 (5.8)	3.7 (0.53)	2.69 (1.15)	0.17 (0.07)	16.7 (4.55)	1.28 (1.12)	0.19 (0.13)	0.07 (0.02)	0.14 (0.11)	21.8 (10.5)	7.4 (4.6)	0.29 (0.14)	0.23 (0.16)	0.20 (0.12)	0.31 (0.24)
Bf*	115	30.0 (15.2)	4.8 (0.40)	1.68 (0.66)	0.11 (0.13)	17.7 (8.47)	1.60 (2.94)	0.29 (0.37)	0.07 (0.04)	0.09 (0.07)	10.5 (8.6)	13.4 (17.7)	0.82 (0.48)	1.25 (0.67)	0.27 (0.16)	0.59 (0.30)
Bm	3	14.3 (3.21)	4.9 (0.26)	0.39 (0.10)	0.04 (0.01)	10.6 (3.14)	0.88 (0.52)	0.23 (0.09)	0.05 (0.01)	0.37 (0.01)	0.6 (1.6)	13.6 (5.4)	0.8 (0.04)	0.71 (0.15)	0.91 (0.03)	0.23 (0.03)
BC	2	25.0 (21.2)	5.1 (0.07)	1.02 (0.28)	0.18 (0.25)	8.3 (6.0)	0.49 (0.88)	0.12 (0.23)	0.06 (0.02)	0.06 (0.03)	6.9 (1.5)	9.8 (11.3)	0.45 (0.34)	2.81 (1.75)	0.07 (0.04)	0.59 (0.28)
Master layers and horizons:																
LFH	50	8.4 (5.2)	3.5 (0.92)	43.3 (8.82)	1.19 (0.37)	39.0 (11.9)	19.8 (12.0)	3.70 (1.74)	0.63 (0.47)	2.25 (1.33)	99.1 (43.4)	30.5 (21.4)	- -	- -	- -	- -
A	35	9.6 (6.9)	4.2 (0.63)	4.56 (2.61)	0.25 (0.15)	18.6 (5.86)	4.93 (5.85)	0.62 (0.57)	0.21 (1.34)	0.19 (0.13)	29.4 (16.4)	19.5 (18.5)	0.80 (0.60)	0.61 (0.53)	0.42 (0.32)	0.51 (0.35)
B	120	29.1 (15.3)	4.8 (0.40)	1.71 (1.00)	0.12 (0.14)	17.5 (8.47)	1.56 (2.86)	0.25 (0.36)	0.07 (0.04)	0.09 (0.07)	18.6 (0.64)	13.2 (17.2)	0.83 (0.50)	1.30 (0.79)	0.26 (0.17)	0.61 (0.35)

[1] Numbers in parenthesis are standard deviations.

The marginal podzolic character of these soils, especially those derived from base-rich parent materials in the climatic environment of the CWHal Variant, has caused inconsistencies in their classification as Podzols. For instance Kojima (1971), using the NSSC (1970) criteria, classified the majority of low elevation soils in Strathcona Provincial Park as Dystric Brunisols. Using the CSSC (1978) pyrophosphate Fe and Al criterion, the comparable soils in the Cameron River Valley were classified as Dystric Brunisols or (Humo-Ferric) Ferric* Podzols. Moon (1981) reported discrepancies between morphological and current chemical criteria in classifying the soils studied in the CWHal Variant on East Vançouver Island. In consequence, he classified a pedon with well expressed podzolic morphological characteristics as a Brunisol on the basis of a low (< 0.6%) content of pyrophosphate Fe and Al in the diagnostic B horizon.

Ferric* Podzols occurred predominantly in the CWHa Subzone where they were found on a variety of sites. The Ah-Podzols grouped in cluster F1 occurred typically on alluvial terraces or steep colluvial slopes. These soils are enriched by moisture and nutrients either supplied by subsurface

seepage flow, surface flow of fine organic and mineral materials, or both. The associated Thuja- or Pseudotsuga-Polystichum communities with Moder or Mull humus forms were very productive and floristically diverse.

The Ae-Podzols grouped in cluster F2 were found mainly on well-drained sites of coarse-skeletal, base-poor, glacial-fluvial, colluvial, or morainal deposits. Low productivity Pseudotsuga-Gaultheria communities were characteristic for drier sites, while more productive Tsuga-Hylocomium communities were characteristic for moderately well drained sites. The associated humus forms were Mors, featuring prominent F horizons (Hemimors or Hemihumimors).

The A-less Podzols grouped in cluster F3 were all found in the CWHal Variant on the moderately well drained sites of colluvial slopes. These soils may be enriched as described above for those in cluster F1 but to a lesser extent. Thus, the productivity of the Pseudotsuga-Polystichum communities was lower and the associated Mormoder or Moder humus forms indicated a somewhat less intensive decomposition rate.

The Use of Organic Layers and Non-Podzolic Mineral Horizons as Differentiae at the Subgroup Level

Tables 9 and 17 show the four identified subgroups in relation to the new great groups. These subgroups, designated as folisolic*, umbric*, albic*, and spodic*, were based on the presence or absence and degree of expression of the LFH layer and Ah and Ae horizons. The rationale for their recognition was discussed earlier.

Folisolic* Subgroups

Three clusters (A, C1, and D1) in two of the new great groups were found to have pedons with thick subsurface organic H or Oh horizons (Table 17). Some characteristics of these horizons diagnostic for folisolic* subgroups or phases are presented in Table 30. In the soils of this study the surface organic layers averaged approximately 25 cm in thickness and H horizons were notable mostly for their relatively low pH and wide C/N ratio. The soils found to have these thick surface organic layers were located in the coolest and wettest subzones of this study. These soils rarely freeze nor completely dry and under these conditions, the accumulation of organic forest floor material can be considered as one of the dominant soil forming processes (Trowbridge 1980).

Trowbridge (1980) pointed out that soils consisting of thick L, F, and H horizons but underlain by unconsolidated, non-fragmental mineral soil are classified on the basis of soil development in the mineral material, regardless of the thickness of the overlying organic horizons. Yet due to the thickness of the surface organic horizons, the characteristics of the underlying mineral soil are often of lesser importance for tree growth and related silvicultural activities. Trees and undergrowth are dominantly rooted in the organic material, most biological activity seems to be centred there, and land management is related much more strongly to the organic surface horizons than to the underlying soil. Consequently, the classification system should be able to identify soils with these thick organic surface horizons at either the phase or, preferably, subgroup level.

At present, the CSSC (1978) defines Folisols as consisting of well to

TABLE 30. Weighted means and standard deviations[1] of some chemical properties of subsurface H or Oh horizons diagnostic for folisolic* subgroups

Tentative great group	Number of H or Oh horizons	Thickness of the LFH layer	pH ($CaCl_2$)	Total C (%)	Total N (%)	C/N	Exchangeable cations Ca	Mg	Na	K (meq/100g)	CEC (meq/100g)	BS (%)
Humic*	9	24.7 (8.84)	3.9 (0.76)	42.6 (10.8)	0.98 (0.34)	46.6 (19.1)	8.23 (17.94)	4.5 (6.04)	0.71 (0.61)	0.52 (0.31)	127.6 (24.6)	10.3 (14.8)
Ferro-Humic*	14	27.2 (9.24)	3.7 (0.61)	43.3 (10.3)	1.30 (0.50)	36.5 (15.8)	14.15 (15.61)	7.46 (6.00)	0.64 (0.38)	0.62 (0.21)	120.2 (37.2)	17.6 (11.5)

[1] Numbers in parenthesis are standard deviations.

TABLE 31. Weighted means and standard deviations[1] of some chemical properties of Ah or Ahe horizons diagnostic for umbric* subgroups

Tentative great group	Number of horizons	Thickness (cm)	pH ($CaCl_2$)	Total C (%)	Total N (%)	C/N	Exchangeable cations Ca	Mg	Na	K (meq/100g)	CEC (meq/100g)	BS (%)	Oxalate-extractable Fe	Al (%)	Pyrophosphate-extractable Fe	Al
Ferro-Humic*	10	15.5 (8.8)	4.3 (0.51)	7.33 (4.40)	0.54 (0.35)	15.1 (7.3)	3.41 (3.98)	0.57 (0.58)	0.11 (0.09)	0.19 (0.15)	39.1 (20.9)	10.4 (8.5)	0.81 (0.30)	1.47 (0.94)	0.61 (0.30)	1.13 (0.70)
Humo-Ferric*	17	8.7 (4.8)	4.3 (0.3)	9.24 (4.07)	0.59 (0.23)	16.1 (4.6)	5.25 (4.13)	0.85 (0.70)	0.13 (0.24)	0.33 (0.40)	47.3 (19.1)	12.9 (8.4)	0.63 (0.46)	0.83 (0.64)	0.43 (0.23)	0.73 (0.40)
Ferric*	21	9.9 (7.6)	4.5 (0.68)	5.72 (2.47)	0.30 (0.16)	19.7 (6.6)	7.20 (6.82)	0.89 (0.58)	0.29 (1.72)	0.23 (0.13)	34.2 (17.5)	26.9 (20.7)	1.11 (0.59)	0.84 (0.56)	0.55 (0.34)	0.62 (0.35)

[1] Numbers in parenthesis are standard deviations.

TABLE 32. Weighted means and standard deviations[1] of some chemical properties of Ae horizons diagnostic for albic* subgroups

Tentative great group	Number of horizons	Thickness (cm)	pH ($CaCl_2$)[2]	Total C (%)	Total N (%)	C/N	Exchangeable cations Ca	Mg	Na	K (meq/100g)	CEC (meq/100g)	BS (%)	Oxalate-extractable Fe	Al (%)	Pyrophosphate-extractable Fe	Al
Ferro-Humic*	12	5.3 (1.9)	3.4 (0.3)	3.75 (3.42)	0.15 (0.23)	27.8 (9.8)	0.90 (2.12)	0.39 (0.94)	0.13 (0.14)	0.30 (0.72)	24.6 (18.0)	5.6 (5.2)	0.55 (0.53)	0.27 (0.13)	0.32 (0.43)	0.21 (0.12)
Humo-Ferric*	34	10.9 (9.2)	3.5 (0.47)	3.70 (1.30)	0.16 (0.11)	20.7 (10.4)	0.76 (1.09)	0.16 (0.13)	0.07 (0.04)	0.21 (0.17)	16.8 (7.9)	7.1 (4.7)	0.16 (0.22)	0.15 (0.24)	0.06 (0.10)	0.13 (0.17)
Ferric*	14	9.1 (5.8)	3.8 (0.53)	1.69 (1.15)	0.17 (0.07)	16.7 (4.5)	1.28 1.12)	0.19 (0.13)	0.07 (0.02)	0.14 (0.11)	21.8 (10.5)	7.4 (4.6)	0.39 (0.14)	0.23 (0.16)	0.20 (0.12)	0.31 (0.24)

[1] Numbers in parenthesis are standard deviations.

imperfectly drained organic forest floor accumulations greater than 10 cm thick overlying a lithic contact or fragmental material. They are classified as a great group of the Organic Order.

Trowbridge (1980) offered three options for the classification of soils with thick surface organic layers. These were:

1. expansion of the current Folisol Great Group of the Organic Soil Order to include soils with thick L, F, and H horizons over unconsolidated mineral material;
2. defining 'folisolic' subgroups for existing great groups in the established soil orders; or
3. defining a new soil order which would consist of folisolic soils.

Common to all of these options is the fact that mineral soils with less than 40 cm of surface organic materials would continue to be classified as at present but should, however, be identified as folisolic phases of their great groups or subgroups. Although Luttmerding (1981) suggests that option 2 is no longer under consideration, the authors of the present study suggest that, taxonomically, option 2 is the most suitable of the options presented. Based on the mean thickness of the LFH layer, the authors of this study would also recommend that folisolic subgroups be recognized for all pedons having LFH layers greater than 15 cm but less than 40 cm thick.

Umbric* Subgroups

The pedons included in the umbric* subgroups (Table 17) were characterized by the presence of umbric horizons greater than 2 cm thick. Some chemical properties of these Ah (or Ahe) horizons diagnostic for umbric* subgroups are given in Table 31. These horizons have relatively high pH's and low C/N ratios. They were found to predominantly occur in soils in the CWHa subzone.

At present, the CSSC (1978) requires that Ah horizons be at least 10 cm thick for qualification as a sombric subgroup of any podzolic great group; similarly, Soil Survey Staff (1975) requires the minimum thickness of 10 cm for an umbric epipedon. Most of the Ah horizons of mesothermal podzols of

this study were less than 10 cm thick. An examination of the mean and standard deviation of the thickness of diagnostic Ah and Ahe horizons suggests that a lower thickness criterion than 10 cm is more appropriate.

Albic* and Spodic* Subgroups

Albic* and Spodic* subgroups are proposed on the basis of presence and absence of the Ae horizon, respectively (Table 17). Some chemical properties of albic horizons for the pedons examined in this study are given in Table 32. These Ae horizons were found to have a much lower pH ($CaCl_2$), total C, total N, exchangeable cations, and cation exchange capacity than Ah or Ahe horizons, with most chemical properties being similar to, or lower than, those of the underlying B horizons. The primary difference between Ae- and A-less Podzols was the low pH of the first surface mineral horizon. The pH of Ae horizons was generally more than a full pH-unit lower than that of the underlying B horizons.

Lewis (1976) states that, as a rule, in an equivalent environment, Ae-Podzols will always have less sesquioxide-rich B horizons than Ae-less Podzols. This was only partly the case for the Podzols examined in this study. Table 33 gives a comparison of chemical properties of master B horizons with and without overlying Ae horizons. No definite trends in sesquioxide concentration were observed in relation to the presence or absence of albic horizons. However, these trends may have been obscured by grouping the soils taxonomically instead of by parent material lithology. When Ae-Podzols and A-less Podzols of the same lithology were examined, as in the case of the mesic Podzols (Table 14), these relationships appear to hold true.

Lewis (1976) also states that, as a rule, Ae horizons do not develop on heterogenous tills but rather on the well-sorted, coarse, siliceous sands, where the content of bases, iron, and even silicates is relatively low. This hypothesis is supported by the findings of this study where over 90% of the pedons having Ae horizons were formed from the granitic parent materials of the areas sampled in the CWHa and CWHb subzones. In tills of mixed lithology the A horizon was either absent, as was often the case in the

CWHb/d ecotone, or an Ah horizon was present, as was usually the case in the CWHa Subzone.

In summary, the use of subgroups identified by the presence, absence, and degree of expression of LFH layers and Ah and Ae horizons is proposed. Podzols with LFH layers greater than 15 cm thick would be designated as folisolic* subgroups, Ah horizons greater than 3 cm thick as umbric* subgroups, and Ae horizons greater than 3 cm thick as albic* subgroups of the respective podzolic great groups. These layers and horizons are of significance for forest soil management and their recognition at the subgroup level would provide relevant information in regard to past and present pedogenic and ecological processes.

TABLE 33. Weighted means and standard deviations[1] of some chemical properties of master podzolic B horizons of albic* and spodic* Podsols

Tentative subgroup cluster	Number of horizons	Thickness (cm)	pH ($CaCl_2$)	Total C (%)	Total N (%)	C/N	Exchangeable cations (meq/100g) Ca	Mg	Na	K	CEC (meq/100g)	BS (%)	Oxalate-extractable (%) Fe	Al	Pyrophosphate-extractable (%) Fe	Al
Ferro-Humic* Podsols:																
Albic* (C2)	10	29.2 (12.5)	4.6 (0.3)	5.79 (2.36)	0.31 (0.13)	19.1 (7.1)	0.27 (0.20)	0.05 (0.04)	0.07 (0.04)	0.10 (0.04)	44.9 (12.0)	1.2 (0.6)	1.07 (0.41)	4.34 (1.74)	0.49 (0.36)	1.75 (0.75)
Luteritic* (B2)	10	28.3 (23.0)	4.6 (0.2)	7.39 (0.99)	0.39 (0.13)	19.9 (4.4)	1.20 (0.94)	0.16 (0.11)	0.08 (0.05)	0.09 (0.09)	47.5 (5.9)	3.4 (3.2)	0.93 (0.23)	2.58 (1.00)	0.81 (0.32)	2.15 (0.64)
Luteritic* (B3)	13	30.4 (17.3)	4.5 (0.3)	4.38 (2.77)	0.22 (0.13)	20.0 (2.9)	1.37 (1.32)	0.19 (0.19)	0.09 (0.03)	0.45 (0.51)	32.0 (19.5)	6.7 (4.3)	0.88 (0.46)	1.92 (1.62)	0.31 (0.20)	0.93 (0.73)
Humo-Ferric* Podsols:																
Albic* (E2)	14	33.7 (23.7)	4.5 (0.5)	5.56 (2.95)	0.34 (0.22)	18.2 (6.9)	1.67 (1.39)	0.18 (0.13)	0.09 (0.04)	0.10 (0.10)	37.4 (10.6)	5.1 (3.6)	0.91 (0.55)	2.36 (1.43)	0.45 (0.25)	1.36 (0.56)
Luteritic* (B3)	20	27.3 (13.8)	4.4 (0.3)	3.86 (0.83)	0.25 (0.13)	22.0 (19.1)	0.21 (0.50)	0.06 (0.06)	0.06 (0.03)	0.12 (0.05)	33.5 (11.3)	1.6 (2.4)	1.14 (0.49)	2.60 (1.34)	0.47 (0.35)	1.29 (0.43)
Albic* (G1)	23	33.4 (16.0)	4.7 (0.3)	1.93 (1.21)	0.12 (0.08)	20.5 (23.8)	0.34 (0.49)	0.05 (0.09)	0.19 (0.18)	0.09 (0.07)	22.6 (9.2)	3.5 (3.8)	0.56 (0.19)	1.78 (0.58)	0.13 (0.10)	0.55 (0.29)
Luteritic* (G3)	16	31.9 (13.9)	4.7 (0.27)	2.77 (1.65)	0.21 (0.15)	14.7 (5.1)	0.44 (0.29)	0.07 (0.07)	0.06 (0.02)	0.12 (0.11)	25.5 (13.3)	3.1 (13.3)	0.58 (1.71)	2.02 (0.23)	0.23 (0.18)	0.83 (0.35)

[1] Numbers in parenthesis are the standard deviations.

SUMMARY

There have probably been more studies on Podzol soils than any other group of soils. Concepts in North America have shifted from surface horizons to subsurface horizons as being diagnostic for Podzols and the emphasis is placed on amorphous constituents in these subsurface horizons as extracted by various methods. The classificiation of Podzols, however, still receives much attention. As ecological programs expand, new relationships are noted among ecological parameters and soil. This is particularly true in British Columbia. Since climate and vegetation play such dominant roles in pedogenesis, the amount and kind of organic matter on and within the mineral soil have a great influence on soil formation and on natural vegetation. This is particularly true of Podzol soils in British Columbia.

This study examined 177 pedons from three locations in coastal southwestern British Columbia. By means of literature review and statistical analyses, four great groups were identified in the group of Podzols rather than the three presently recognized in Canada (CSSC 1978). The classification proposed in this study is based more on organic carbon content than on extractable sesquioxides. This new classification also recognizes three additional subgroups which are based on organic layers, presence of Ah, presence of Ae, and lack of Ae. These parameters have significant silvicultural value and at present are either ignored or labelled as phases. The new classification appears to relate better to climate and lithology of the parent material and thus to vegetation, all of which are pedogenetic factors.

The new proposed classification using total carbon is significantly correlated to sesquioxides; however, in this study total carbon accounted for only 69% of the sum of pyrophosphate-extractable Fe and Al. This leads one to re-examine the mechanisms by which sesquioxides accumulate in Podzol B horizons.

Although the study is based on a climosequence with a range in precipitation from about 1 300 mm to 2 200 mm, with no known or moderate

water deficit, the new classification criteria should be tested on a variety of ecological sites where Podzol soils are found.

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APPENDIX Some chemical properties of mesic mesothermal Podzols.

TABLE 1. Weighted means and standard deviations[1] of some chemical properties for layers and horizons and master layers and horizons of mesic Podzols in the $CWHa_1$ Biogeoclimatic Variant

Layers or horizons	Number of layers or horizons	Thickness (cm)	pH ($CaCl_2$)	Total C (%)	Total N (%)	C/N	Exchangeable cations				CEC (meq/100g)	BS (%)	Oxalate-extractable		Pyrophosphate-extractable	
							Ca	Mg	Na	K			Fe	Al	Fe	Al
							(meq/100g)						(%)			
Layers and horizons:																
LFH	5	7.4	4.1	46.3	1.02	45.8	22.0	3.5	0.28	4.3	70.4	43.1	-	-	-	-
		(1.5)[1]	(0.31)	(4.40)	(0.14)	(3.53)	(16.1)	(0.43)	(0.12)	(2.1)	(9.08)	(21.1)	-	-	-	-
Bfh*	2	8.5	4.4	3.6	0.12	31.4	0.88	0.23	0.10	0.18	19.6	8.7	1.92	2.20	0.53	0.78
		(6.4)	(0.14)	(0.21)	(0.02)	(6.62)	(0.53)	(0.12)	(0.12)	(0.01)	(8.14)	(10.8)	(0.20)	(1.1)	(0.30)	(0.17)
Bf*	8	31.0	4.5	1.9	0.08	23.5	1.30	0.29	0.07	0.12	16.6	11.0	1.30	1.17	0.39	0.62
		(7.4)	(0.20)	(0.72)	(0.02)	(5.81)	(0.49)	(0.11)	(0.03)	(0.06)	(4.65)	(4.15)	(0.34)	(0.36)	(0.15)	(0.17)
Master layers and horizons:																
LFH	5	7.4	4.1	46.3	1.02	45.8	22.0	3.5	0.28	4.3	70.4	43.1	-	-	-	-
		(1.5)	(0.31)	(4.40)	(0.14)	(3.54)	(16.1)	(0.43)	(0.12)	(2.1)	(9.10)	(21.1)	-	-	-	-
B	10	26.5	4.5	2.04	0.08	24.0	1.25	0.28	0.07	0.12	16.7	10.9	1.34	1.24	0.40	0.63
		(11.7)	(0.20)	(0.93)	(0.03)	(6.04)	(0.47)	(0.11)	(0.06)	(0.05)	(4.92)	(5.14)	(0.41)	(0.56)	(0.19)	(0.16)

[1] Numbers in parenthesis are standard deviations.

APPENDIX Some chemical properties of mesic mesothermal Podzols.

TABLE 2. Weighted means and standard deviations[1] of some chemical properties for layers and horizons and master layers and horizons of mesic Podzols in the $CWHa_2$ Biogeoclimatic Variant

Layers or horizons	Number of layers or horizons	Thickness (cm)	pH ($CaCl_2$)	Total C (%)	Total N (%)	C/N	Exchangeable cations (meq/100g) Ca	Mg	Na	K	CEC (meq/100g)	BS (%)	Oxalate-extractable (%) Fe	Al	Pyrophosphate-extractable (%) Fe	Al
Layers and horizons:																
LFH	7	11.1 (10.9)[1]	3.4 (0.19)	51.6 (2.25)	1.54 (0.13)	34.6 (2.99)	14.5 (2.21)	2.54 (0.56)	0.74 (0.29)	1.50 (0.61)	180.7 (56.2)	11.6 (5.7)	- -	- -	- -	- -
Ae	4	6.2 (2.5)	3.3 (0.14)	2.21 (0.78)	0.13 (0.04)	16.8 (3.29)	0.38 (0.11)	0.11 (0.36)	0.07 (0.01)	0.13 (0.09)	20.3 (10.5)	4.4 (2.9)	0.23 (0.10)	0.09 (0.03)	0.10 (0.07)	0.15 (0.06)
Bf*	14	36.1 (17.2)	4.7 (0.19)	1.72 (0.53)	0.11 (0.02)	15.8 (2.94)	0.23 (0.12)	0.03 (0.01)	0.05 (0.02)	0.05 (0.01)	20.3 (8.7)	2.1 (1.4)	0.51 (0.22)	1.52 (0.56)	0.17 (0.07)	0.66 (0.15)
Master layers and horizons:																
LFH	7	11.1 (10.9)	3.4 (0.19)	51.6 (2.25)	1.54 (0.13)	34.6 (2.99)	14.5 (2.21)	2.54 (0.56)	0.74 (0.29)	1.50 (0.61)	180.7 (56.2)	11.6 (5.74)	- -	- -	- -	- -
A	5	5.4 (2.9)	3.3 (0.29)	2.90 (4.72)	0.16 (0.23)	17.0 (3.23)	0.89 (3.06)	0.17 (0.32)	0.07 (0.02)	0.16 (0.20)	26.2 (36.2)	4.7 (3.2)	0.22 (0.10)	0.89 (0.04)	0.11 (0.08)	0.16 (0.09)
B[2]	16	33.5 (17.5)	4.7 (0.20)	2.03 (1.89)	0.12 (0.09)	16.0 (3.04)	0.23 (0.19)	0.03 (0.01)	0.05 (0.02)	0.06 (0.02)	21.5 (12.1)	2.1 (1.4)	0.56 (0.45)	1.65 (1.04)	0.19 (0.13)	0.68 (0.44)

[1] Numbers in parenthesis are standard deviations.

[2] Values of the master podzolic B horizon include data of one Bhf* and one Bfh* horizons which are not presented in this table.

APPENDIX Some chemical properties of mesic mesothermal Podzols.

TABLE 3. Weighted means and standard deviations[1] of some chemical properties for layers and horizons and master layers and horizons of mesic Podzols in the $CMHb_2$ Biogeoclimatic Variant

Layers or horizons	Number of layers or horizons	Thickness (cm)	pH ($CaCl_2$)	Total C (%)	Total N (%)	C/N	Exchangeable cations				CEC (meq/100g)	BS (%)	Oxalate-extractable		Pyrophosphate-extractable	
							Ca	Mg	Na	K			Fe	Al	Fe	Al
							(meq/100g)						(%)			
Layers and horizons:																
LFH	9	13.6 (3.0)[1]	3.2 (0.15)	50.9 (3.71)	1.19 (0.29)	42.5 (9.01)	9.28 (3.86)	2.66 (0.70)	0.70 (0.43)	2.76 (1.07)	114.1 (16.1)	13.8 (3.89)	- -	- -	- -	- -
Ae	10	13.9 (7.9)	3.1 (0.11)	2.52 (1.04)	0.20 (0.18)	17.2 (6.94)	0.32 (0.27)	0.13 (0.06)	0.07 (0.02)	0.33 (0.25)	12.8 (3.93)	7.1 (3.2)	0.12 (0.10)	0.07 (0.03)	0.03 (0.03)	0.06 (0.05)
B/h*	6	23.3 (13.2)	4.3 (0.31)	4.29 (1.20)	0.19 (0.14)	41.7 (29.9)	0.10 (0.06)	0.06 (0.02)	0.06 (0.01)	0.12 (0.05)	31.5 (8.78)	1.12 (0.40)	1.28 (0.37)	1.98 (1.05)	0.62 (0.45)	1.11 (0.46)
Bf*	6	18.0 (8.9)	4.6 (0.33)	2.19 (0.62)	0.12 (0.04)	18.3 (2.16)	0.13 (0.07)	0.03 (0.02)	0.05 (0.09)	0.05 (0.03)	22.6 (9.12)	1.4 (1.1)	0.67 (0.39)	1.89 (1.18)	0.17 (0.19)	0.72 (0.86)
Master layers and horizons:																
LFH	9	13.6 (3.0)	3.2 (0.15)	50.9 (3.71)	1.19 (0.29)	42.5 (9.01)	9.28 (3.86)	2.66 (0.70)	0.70 (0.43)	2.76 (1.07)	114.1 (16.1)	13.8 (3.89)	- -	- -	- -	- -
A	10	13.9 (7.9)	3.1 (0.11)	2.52 (1.04)	0.20 (0.18)	17.2 (6.94)	0.32 (0.27)	0.13 (0.06)	0.07 (0.02)	0.33 (0.25)	12.8 (3.93)	7.1 (3.2)	0.12 (0.10)	0.07 (0.03)	0.03 (0.03)	0.06 (0.05)
B	12	20.7 (11.1)	4.4 (0.36)	3.38 (1.51)	0.16 (0.10)	31.5 (23.0)	0.12 (0.07)	0.05 (0.02)	0.06 (0.01)	0.09 (0.05)	27.6 (9.43)	1.3 (0.8)	1.01 (0.44)	1.94 (1.07)	0.42 (0.37)	0.94 (0.66)

1 Numbers in parenthesis are standard deviations.

APPENDIX Some chemical properties of mesic mesothermal Podzols.

TABLE 4. Weighted means and standard deviations[1] of some chemical properties for layers and horizons and master layers and horizons of mesic Podzols in the CMHb/d ecotone

Layers or horizons	Number of layers or horizons	Thickness (cm)	pH ($CaCl_2$)	Total C (%)	Total N (%)	C/N	Exchangeable cations				CEC (meq/100g)	BS (%)	Oxalate-extractable		Pyrophosphate-extractable	
							Ca	Mg	Na	K			Fe	Al	Fe	Al
							(meq/100g)						(%)			
Layers and horizons:																
LF	6	13.3 (10.7)[1]	3.12 (1.50)	50.7 (2.98)	1.04 (0.21)	49.58 (11.0)	13.4 (7.87)	6.60 (4.42)	0.72 (0.52)	1.41 (1.89)	76.5 (49.5)	17.3 (20.7)	- -	- -	- -	- -
H or OH	4	17.3 (5.9)	3.3 (1.7)	53.19 (4.64)	1.3 (0.50)	42.9 (13.9)	8.44 (5.57)	9.01 (4.56)	0.98 (0.55)	6.1 (0.21)	132.2 (14.9)	14.2 (6.78)	- -	- -	- -	- -
Ae	3	2.7 (1.2)	3.5 (0.6)	6.58 (6.60)	0.31 (0.46)	29.6 (10.5)	2.73 (4.12)	1.45 (1.68)	0.24 (0.26)	0.69 (1.47)	33.0 (28.3)	11.3 (8.63)	0.54 (0.53)	0.26 (0.21)	0.51 (0.53)	0.18 (0.14)
Bhf*	7	28.7 (12.7)	3.9 (0.3)	7.32 (1.35)	0.23 (0.07)	32.8 (4.35)	0.65 (0.50)	0.30 (0.17)	0.21 (0.11)	0.09 (0.05)	43.3 (12.0)	2.9 (1.21)	2.8 (1.62)	2.1 (1.74)	2.2 (1.22)	1.50 (0.70)
Bfh*	4	27.5 (14.3)	4.4 (0.5)	3.94 (0.70)	0.13 (0.03)	29.0 (2.01)	0.96 (0.78)	0.17 (0.27)	0.16 (0.02)	0.06 (0.04)	30.8 (2.54)	4.3 (2.38)	1.83 (0.55)	2.86 (0.81)	0.85 (0.36)	1.33 (0.11)
Master layers and horizons:																
LFH	10	20.2 (11.1)	3.2 (1.4)	52.4 (4.49)	1.19 (0.41)	46.3 (12.1)	11.6 (4.91)	8.02 (4.14)	0.79 (0.48)	1.01 (1.93)	116.3 (18.1)	15.8 (18.1)	- -	- -	- -	- -
A	3	2.7 (1.2)	3.5 (0.6)	6.58 (6.60)	0.31 (0.46)	29.6 (10.5)	2.73 (4.12)	1.45 (1.68)	0.24 (0.26)	0.69 (1.47)	33.0 (28.3)	11.3 (8.63)	0.54 (0.53)	0.26 (0.31)	0.51 (0.53)	0.18 (0.14)
B	11	26.4 (13.6)	4.1 (0.37)	6.23 (2.85)	0.20 (0.11)	31.3 (3.69)	0.80 (0.61)	0.32 (0.23)	0.20 (0.09)	0.08 (0.06)	39.5 (13.8)	3.4 (1.8)	2.44 (1.32)	2.41 (1.40)	1.76 (1.15)	1.47 (0.66)

[1] Numbers in parenthesis are standard deviations.